SPATIAL DISTRIBUTION OF THE LEVELS OF TRACE METALS IN THE TOPSOIL OF DAMMAM AREA, EASTERN PROVINCE OF SAUDI ARABIA

BY

ADETORO JOHN ADEDAPO

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DEANSHIP OF GRADUATE STUDIES

This thesis, written by Adetoro John Adedapo under the direction his thesis advisor and approved by his thesis committee, has been presented and accepted by the Dean of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE.**

Dr. Bassam Shafiq Tawabini
(Advisor)

Dr. Abdulaziz Al-Shaibani
Department Chairman

Dr. Abdulaziz Al-Shaibani
(Member)

Dr. Salam A. Zummo
Dean of Graduate Studies

Prof. Ahmet Umran Dogan
(Member)

10/12/14
Date

This thesis is dedicated to a friend like a brother, Late Ayinde Adetoyese Oyetunde

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LIST OF ABBREVIATIONS

ICP-OES:	Inductively Coupled Plasma - Optical Emission Spectrometry.
GPS:	Global Positioning System.
GIS:	Geographic Information System.
IARC:	International Agency for Research on Cancer.
ACGIH:	American Conference of Governmental Industrial Hygienist.
TSC:	Trask Sorting Coefficient.
Cu:	Coefficient of Uniformity.
Cc:	Coefficient of Curvature.
ID:	Industrial area samples.
AG:	Agricultural area samples.
R:	Residential area samples.
BG:	Background samples.

ABSTRACT

Full Name: John Adedapo Adetoro

Thesis Title: Spatial distribution of the levels of trace metals in topsoil of Dammam area, Eastern Province of Saudi Arabia.

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The soil ability to retain toxic trace metals from various sources has proven to be a threat to human health and ecological systems, and this necessitates the assessment of the health condition of the soil. The main objective of this study is to produce geochemical maps of trace metals concentration and identify areas of high metal concentration 'hot spots' in the topsoil of Dammam area, the Eastern Province of Saudi Arabia. A total of 132 representative topsoil samples were collected from selected Dammam's residential, industrial, agricultural, and background (reference site) areas and analyzed for their structure and concentration levels of trace metals. The results showed that the mean concentration levels of the trace metals were as follows: Arsenic (As) (1.21±0.69 mg/kg), Barium (Ba) (110.62±262 mg/kg), Cadmium (Cd) (1.18±4.33 mg/kg), Chromium (Cr) (31.79±37.9 mg/kg), Cupper (Cu) (6.76±12.54 mg/kg), Mercury (Hg) (0.08±0.18 mg/kg), Nickel (Ni) (8.95±5.66 mg/kg), Lead (Pb) (6.34±14.55 mg/kg), Titanium (Ti) (119.27±85.74 mg/kg), Vanadium (V) (9.98±6.08 mg/kg), and Zinc (Zn) (23.44±84.43mg/kg). The levels of As, Ba, Hg, Pb, Ni, and V were within the international allowable limits usually found in topsoil, while Cd, Cr, Cu, and Zn exceeded the allowable limits with industrial and residential areas having the highest concentrations. The elevated levels of trace metals in some locations may be attributed to atmospheric deposition and related to activities capable of discharging such pollutants.

ملخص الرسالة

الاسم الكامل: جون أديدابو أديتورو

عنوان الرسالة: التوزيع المكاني لمستويات العناصر النادرة في الجزء العلوي من التربة، منطقة الدمام، المنطقة الشرقية، المملكة العربية السعودية.

التخصص: العلوم البيئية

تاريخ الدرجة العلمية: يناير 2015

قابلية التربة على الامتصاص والاحتفاظ بالعناصر النادرة السامة من عدة مصادر يمثل خطرا محتملا على الانسان والنظام البيئي ككل، الامر الذي يتطلب تقييم الحالة الصحية للتربة. هذه الدارسة تهدف الي اخراج خرائط جيوكيميائية لتركيز هذه العناصر والتعريف بالمناطق التي تحتوي على تراكيز اعلى للعناصر النادرة في منطقة الدمام، المنطقة الشرقية، المملكة العربية السعودية. لهذا الغرض، تم تجميع 132 عينة ممثلة للجزء العلوي من التربة من عدة مناطق حول الدمام. تم تجميع العينات من المناطق السكنية، الصناعية، والزراعية، بالإضافة الي عينات مرجعية جمعت من مناطق غير متأثرة كسابقتها. أظهرت النتائج ان متوسط مستويات التراكيز لهذه العناصر كانت كالاتي: الزرنيخ (1.21± 0.69 ملغم/كجم)، الباريوم (110.62± 262 ملغم/كجم)، الكادميوم (1.18±4.33 ملغم/كجم)، الكروم (31.79± 37.9 ملغم/كجم)، النحاس (6.76± 12.54 ملغم/كجم)، الزئبق (0.08± 0.18 ملغم/كجم)، النيكل (8.95± 5.66 ملغم/كجم)، الرصاص (6.34± 14.55 ملغم/كجم)، التيتانيوم (119.27±85.74 ملغم/كجم)، الفناديوم (9.98±6.08 ملغم/كجم)، والزنك (23.44± 84.43 ملغم/كجم). مستويات الزرنيخ، الباريوم، الزئبق، الرصاص، النيكل، والفناديوم كانت متوافقة مع الحد العالمي المتوقع تواجده بالجزء العلوي من التربة. من ناحية أخرى، أظهرت النتائج ان بعض العناصر النادرة كالكادميوم، الكروم، النحاس، والزنك تخطت المستويات المتوقعة للتواجد في كل من المنطقتين الصناعية والسكنية حيث وجدت بتراكيز عالية. هذه المستويات المرتفعة في بعض المناطق قد تعزى للترسيب الجوي وما يتبعه من نشاطات صناعية قادرة على تكديس مثل هذا النوع من الملوثات.

CHAPTER 1

INTRODUCTION

1.1 Background

Soil occurs naturally in the environment due to weathering activities of rock materials and are usually in layers that are basically mixed with minerals and organic matter which varies from the original rock materials (parent material) in terms of size, texture, structure, consistency, color, chemical, biological, and other characteristics (Duffus, 2002). Topsoil is the uppermost layer of soil, usually the first 20 cm of the earth's surface, containing a higher percentage of organic matter with various microorganisms and where most of the earth biological activities occurs. Soil pollution came to the forefront of public attention recently (Edward, 2003) and usually occurred when materials detrimental to people, and other living things are inadvertently or deliberately applied to soils. The proper protection and preservation of soils is expected to be a primary objective of environmental monitoring and policy. Soil is limited, non-renewable, and increasingly scarce resources containing various biological, physio-chemical properties. Soil should be protected and preserved in such a way that the ecological balance can be maintained, and ecological functions are served. Soil is necessary for environmental interaction as it serves as a filter and a buffer system against chemical degradation by pollutants such as trace metals, pesticides, organic pollutant, and others.

The city of Dammam is the capital city of the Eastern Province of Saudi Arabia. It is regarded as the largest oil region in the world housing the judicial, administrative, several government

departments, and the majority of the province population. Its closeness to the Arabian Gulf makes it a good tourism center with a variety of entertainment activities available in the area. It has a total area of 800 km², located in the desert with hot climate. Warm temperature is usually experienced in the winter and it ranges from +10°C to +22°C (WMO, 2011) and temperature as low as 0°C can be experienced for a few days. The average summer temperature in the region usually lies between 40°C to 45°; however, extremely high temperature (45°C to 50 °C) occurs. Rainfall is sparse, and occurs usually in small amounts in the period of November to March.

Trace metals are elements that are available in relatively small amounts in soils or parental rock materials. It exists naturally in the ecosystem with large variations in terms of its concentration (Allen et al., 2001). Recently, human activities have increased the rate of pollution which has also contributed to the increase in the levels of trace metals in our environment. Living organisms (plants and animals) require different amounts of trace metals such as Fe, Co, Cu, Mn, and Mo. On the other hand, high levels of trace metals can have negative effects on the organism. However, some trace metals such as Hg, Pu, and Pd has been established to be toxic metals and their accumulation over time in human bodies can be damaging (ATSDR, 1999, 2005).

Al- Kashman and Shawabkeh (2009) reported that Cu, Fe, Pb, Ni, and Zn are the most common reported trace metals in soil with regards to potential hazards. Concentration of trace metals such as Pb, Cd, Zn, and Cu in surface soils have been a focus of investigation and assessment over the past decade (Adriano, 1986) and their accumulation in topsoils has been established to be influenced by traffic volume among other factors. For instance; Pb, has been regarded as a pollutant of concern because of its use as fuel additives. Other heavy metals associated with vehicular emissions are Cu and Zn. Copper comes mainly from brake lining wear and Zn from tire wear. At present, very little is known about the heavy metal concentrations, distribution and extent

of environmental pollution in the soils of Dammam and its environment. However, the present research has assessed the trace metal concentration and their spatial distribution in Dammam area.

Toxic nature of trace metals has the potential to damage or abridge mental and central nervous function, lessen energy levels in the body, and damage the blood composition of lungs, kidneys, liver, and other vital organs in the body. Exposure to these trace metals over a long period may also result to a slowly progressing physical, muscular, and neurological degenerative processes like that of Alzheimer's disease, Parkinson's, muscular dystrophy, and multiple sclerosis (WHO, 2007). There are also reported cases of allergies to some of these metals and continuous long time exposure to some of these metals, or their compound has been established to cause cancer.

Urbanization and industrial revolution have brought about the increase in pollutant level in our environment and most of such pollutants are toxic trace metals coming from different sources including uncontrolled factory emissions, municipal residue disposal, vehicular emission, vehicle aging, and wearing, etc. Eastern province of Saudi Arabia, in general, and Dammam City, in particular, has experienced rapid urbanization and industrialization in recent decades. Trace metals do not decay easily and have potential for bioaccumulation and bio-magnifications causing heavier exposure in the environment. Hence, there is a need to assess the concentration of toxic trace metals in the topsoil in order to be able to improve the quality of life and standard of living.

Geographic Information System (GIS) has become an increasingly important tool in environmental planning, assessment, management and modeling. The GIS is a computer-based tool for mapping and analyzing geographic phenomena that exists, and events that occur, on Earth (David and Fort, 1997). It can also be referred to as a computerized system that facilitates the phases of data entry, data analysis and data presentation, especially in cases of dealing with geo-referenced data (Rolf

et al., 2001). The ability to incorporate spatial data, to manage, to analyze, and answer spatial questions are the distinctive characteristic of the GIS. The introduction of GIS to this project has helped in spatial interpolation and modeling of contaminants in the topsoil and were used to identify higher risk site based on GIS analysis.

1.2 Statement of the Problem

City of Dammam and its environment can be regarded as the center for Saudi Arabia oil production, petrochemical industry, and other industries. The region has also witnessed a dramatic increase in urbanization. Trace metal release into the environment has been attributed to many factors, including urbanization, fossil fuel combustion, industrial waste, uncontrolled factory emission, and vehicular emission. Research on the soil environment is necessary for sustainable development and improvement of the quality of life. However, there is very little information available regarding toxic metal contamination of topsoil in the Dammam area. Hence, there is a need to assess the topsoil in the area to determine trace metal concentration, their 'hot spot' (area of high concentrations of trace metals), and spatial distribution. These will help in assessing the health conditions of the topsoil in the region and may later be used for setting up remediation measures or land use allocations.

1.3 Significance of the Study

In recent years, the general wellbeing of individuals and societies has gained attention of the international community and such wellbeing cannot be evaluated based only on wealth and employment, but most importantly on the built environment, physical and mental health of the individual. Dammam area is characterized with extreme weather conditions, and has seen major urbanization and industrialization associated with the discovery and production of oil and gas, and

has, therefore, witnessed dramatic changes in recent years. Industrialization has led to the urbanization of the area and this necessitates the assessment of the topsoil in the area since most of the industry in the region has the potential of releasing toxic trace metals into the surrounding environment. The concern for groundwater interaction with contaminated soil is also of great importance in this respect. This study aims to produce spatial concentration of trace metals in the topsoil of the area, the "hot spot" area, and the spatial distribution of the contaminant which will enable the authority to check the activities of the companies and provide the general public with a good quality of life. The study may also create further research in the area of environmental assessment and monitoring.

1.4 Research Objectives

The research aims to produce geochemical maps of trace metals concentration and identify likely "hot spots" in the topsoil of Dammam area, eastern province of Saudi Arabia while the objectives include the following:

- To ascertain the concentration of trace metals in the topsoil of selected zones in Dammam area.
- To assess the spatial distribution of trace metals in the topsoil and identify "hot spots" areas.

1.5 The Study Area

The study area for this project is Dammam area. Dammam is the official seat of government in the Eastern Province of Saudi Arabia, probably the most oil-rich region in the world. The area was divided into four different regions which include residential area, industrial area, agricultural area, and background samples. Background samples were taken from an area of no physical development while agricultural, residential, and industrial samples were taken where such activities take place. Since there is no agricultural area in Dammam city, Al-Qatif agricultural area, a suburb of Dammam was chosen. Thirty three (33) representative samples were taken from each area, which sum up to a total of 132 samples.

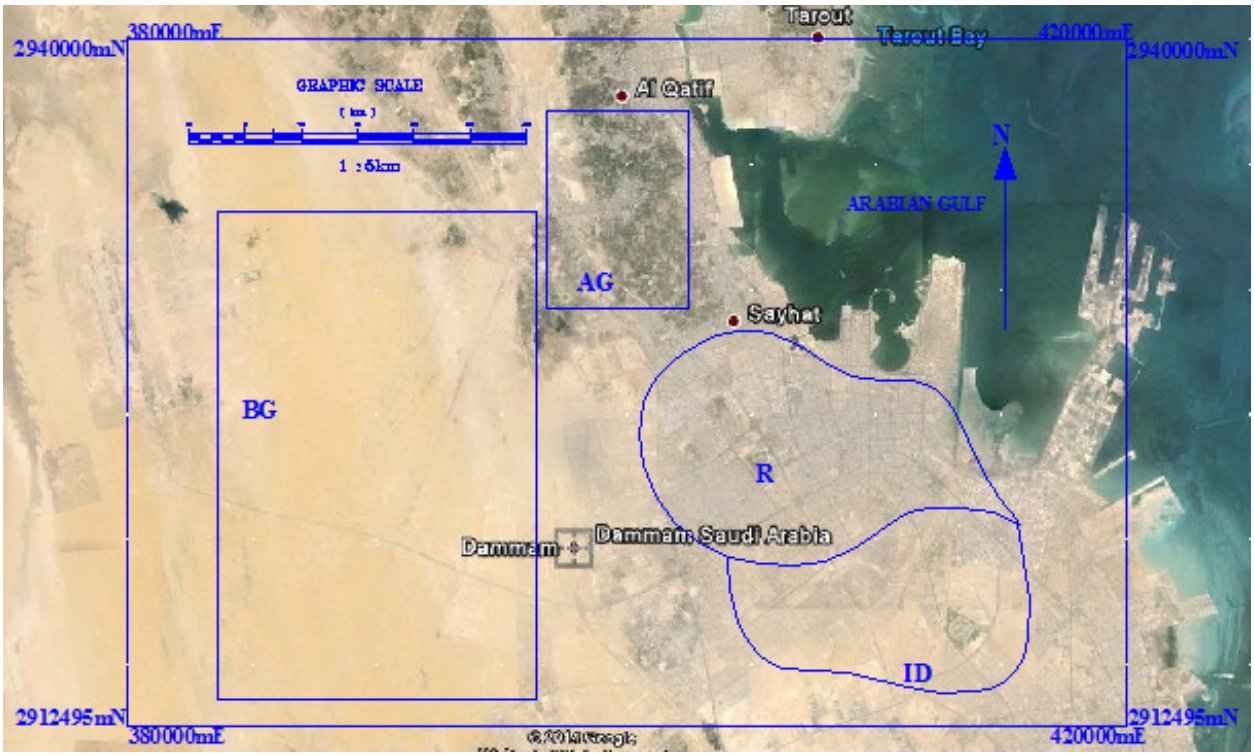

Figure 1.1 Location of the Study Area shown on top of a Google Earth satellite image.

CHAPTER 2

LITERATURE REVIEW

2.1 Trace Metals in the Environment

Trace metals are metals/ elements that are available in relatively small amounts in soil and rocks, either naturally or due to human activities on the earth's surface (Alloway, 1995). Trace metals, as defined by geologists in terms of parental rock materials, as a metal or elements present in rock materials aside the most abundant eight elements available in the earth's crust (Thornton, 1995). Trace metals cannot necessarily be defined in terms of weight as some of the elements are lighter than carbon and the list also exclude some of the heaviest metals. However, the metals are naturally available in the ecosystem with differences in concentration and human-induced sources such as pollution are not left out (Suthar et al., 2009).

Oil that helped the economy and accelerated the pattern of modernization and industrialization is considered one of the sources of trace metal release. Motor gasoline consumption in Saudi Arabia has increased from 150,000 barrels per day in 1986 to 420,000 barrels per day in 2010 (USEIA, 2012). Petrol used in the Kingdom also contains lead additives (Al-Hobaib et al., 2011) which also establish motor vehicle emission as another source of trace metal emission. Meteorological features also influence trace metal concentration in our environment. High wind velocity will accelerate the transportation of particles. Saudi Arabia experience scarce rainfall and the strong wind are usually associated with heavy dust fall, which facilitate the dispersion of toxic trace metals into our environment.

High levels of trace metal concentration in soil can find its way to the groundwater. These materials can penetrate to the groundwater via various routes (Barcelona et al., 1990; Salomons, 1995). Such routes include: interactions of the metals with geologic formations, interactions of groundwater with the surface that contain such metals, percolation of precipitation water containing dissolved, colloidal, and suspended materials, direct access from the land surface via wells.

The trace metals are available in the atmosphere at elevated level as a result of various industrial activities since the naturally occurring atmospheric concentrations are low; they are responsible for the deposition and build-up in soils. There is a possibility of trace metals to bio-accumulate in the food chain because of their persistent nature in the environment. (WHO, Europe, 2007). Trace metals released from either stationary or mobile sources can get access into water, air, soil, and even plants, animals, and human bodies (Adriano, 2001). Trace metals have drastic effects on both human and environment. They can also accumulate in the topsoil through atmospheric deposition. Topsoil can be used as an indicator of trace metal pollution in our environment (Li et al., 2001).

Trace metals can come from different sources (Rodriguez-Salazar and Morton-Bermea, 2011). Thorpe and Harrison (2008) explains how trace metals generated through vehicular exhaust, tire, and brake abrasion find their way to the topsoil by means of either wet or dry atmospheric deposition. They also emphasize the likelihood of those who regularly utilize the sidewalks and those who reside close to the road in urban and rural areas to be exposed to high levels of trace metals concentration. Fergusson and Ryan (1984) also explain the possibility of finding a high level of trace metals on roads where traffic usually undergo stop and start maneuvers such as at traffic lights.

2.2. Trace Metals in Soil

Trace metals in soils originate from the decomposition of geologic rock materials by natural processes and tend to be motionless. The levels of such metals in soils depend upon the overlying rock material based on the motionless characteristics of the trace metals. Adriano (1986), reviewed the effect of soil nature on the concentration of trace metals available by carefully examining different studies by different soil scientist over the years. He stated that seven factors are responsible for the fate and transport of trace elements in the soil, which include; (i) the pH of the soil, (ii) cation exchange capacity (CEC), (iii) anion exchange capacity (AEC), (iv) content of the organic matter, (v) content of the clay and clay type, (vi) oxide content and type, and (vii) redox potential. Trace element absorption/adsorption relies on pH and depends on the availability of the element either in anionic or cationic form. Cation sorption appreciates with increase pH by showing a rapid increase within a small pH range, which is referred to as the adsorption edge. Anion sorption also indicates maximum, when the pH is equal to the pKa of the corresponding acid. This phenomenon is known as the adsorption envelope.

Apart from parent rock materials, there are also several sources of trace metals in the soil. Such sources include sewage sludge incineration, fossil fuel combustion, application of fertilizers and pesticides in agricultural area, etc. Accumulation of trace metals in soil through decomposition of parental rock is of great concern for the environment, so also is the possibilities of human induced activities to elevate the levels of trace metals in the soil. There are reported cases of trace metals in industrial goods, byproducts of the mining industry, constituent substance of paint and pesticides, and as a component of land either in municipal waste or industrial waste. Also, there are reported cases of trace metals in soil via the addition

of inorganic fertilizers, open dumping of industrial waste, atmospheric emission, and spills. The use of trace metals in industry and other area extensively has made it become part of the environment which increases the possibility of the metals to have a negative impact on the environment. For example, the United States has banned the use of materials suspected to elevate trace metals content in the soil by the enactment of regulations to that effect. For instance, the United States Environmental Protection Agency (USEPA) has set some limits for trace metals that should be available in bio-solid before approval can be granted for land spreading (USEPA, 2006).

Trace elements are considered harmful to human and environment in general at an elevated level and long exposure. The average value of cadmium (Cd) levels in the topsoils of the world varies between 0.07 and 1.1 mg/kg but values above 0.5 mg/kg are said to reflect anthropogenic sources based on the data collected from different part of the world (Kabata-Pendias and Pendias, 1984). Thornton et al. (1995) establish the possibility of Cd content in the soil to be close to 30 mg/kg in soil that originate from anomalous rock materials. However, the possibility of Cd available in soil to leach is very minimal, so also is the possibility of uptake by plants. In the United States, a concentration of Cd in unpolluted soil is put at 0.25 mg/kg (ATSDR, 1999); the United Kingdom estimate the Cd level in their soil to be 0.53 mg/kg as at 1987/1988; Japan with 0.4 mg/kg; and European topsoil Cd levels was said to be 0.03-0.8 mg/kg with the median value of 0.14 mg/kg (Thornton, 1992).

In the European Economic Community, 0.5 kg/km² is the allowable level of Cd expected to be present in fertilizer that can be applied to the land. Any value exceeding the stipulated allowable limit is seen as pollution and may elevate the naturally occurring Cd in soil (WHO/IPCS, 1992). Countries like Sweden estimated 0.2% increase per year in the level of

Cd in agricultural soil despite the discouragement of the use of phosphate fertilizer (Jarup et al, 1998). However, trace metals in the industrial area and those close to industrial area are expected to be at elevated levels depending on the type of industrial activities, for instance, Cd level in Helena, U.S.A, which happen to be Smelter Company was found to be 72 mg/kg within and 1.4 mg/kg between 18 and 60 km (ATSDR, 1999). The Cd level in drinking water was always considered less important because it's usually found at very low concentration, usually 1 μg/l (WHO/IPCS, 1992) and the World Health Organization (1993) recommend that Cd level in drinking water should not exceed 3 μg/l for any reason. Therefore, it is necessary to access the levels of trace metals in the soil close to our drinking water source.

Lead (Pb) that serves as gasoline additives to minimize the possibility of an automobile engine knock has become available in the soil and thereby elevated the naturally occurring Pb in some cases. There are also other means in which Pb get into our environment, including contamination from Pb in the paint, insecticide, smelters, and Pb- arsenate. Ewers and Schlipkoter (1991) classify Pb as a toxic substance with potential adverse effect on human, and children as the most affected and possibility of damaging the central nervous system, causing delay and even death in extreme cases.

Ewers and Schlipkoter (1991) also explain the potential for trace metals to bio-accumulate in the food chain. They cited a case of Minamata disease that occurred in Japan as a result of methyl mercury (Hg) bio-accumulation in the fish of Minamata bay and the resident of the area consumed the fish that contain high level of methyl Hg. Another case of trace metal accumulation was recorded in Japan, which cause Itai- Itai disease, a form of Cd poisoning, In this case, the Japanese that consumed the contaminated rice fall ill (Ewers and Schlipköter, 1991).

Pierzynski (1998), expresses concern about the use of total concentration of trace metals in soil as a measure of their bioavailability in soil. He sees it as an inadequate measure of bioavailability and explains the dependence of trace metals on some particular characteristics of soil such as the soil pH and organic content of the soil. He further explains based on the research that two soils of the same concentration of trace metals may have different bioavailability. The importance of trace metal bioavailability was also based on the possibility of a small amount of the trace metals to harm plants and animals. In the event of remediation alternatives, the best possible remediation techniques should be chosen and such techniques should be able to minimize or possibly prevent health hazard by focusing on the availability of trace metals and not the total trace metals concentration in the soil. For instance, in a situation where a trace metals of concern were found in a non-mobile soil, the exposure to plants and animal in such soil will be reduced and this may be seen as a reason why it's necessary for regulatory body address trace metal bioavailability and not its total element concentrations.

The background levels of trace metals in soil or any other materials of the earth are very important for effective assessment of such materials and the correctness of the data should also be taken into consideration because incorrect data can misguide the legislator and force them to set unrealistic allowable limit (Davies, 1992). The existence of a reliable background level with an appropriate database will ensure the enactment of appropriate legislation, thereby, making it realistic and achievable. The importance of establishing the background level of trace metals concentration necessitated countries like the United States (Shacklette and Boerngen, 1994), Belgium as reported by (De Temmerman et al., 1984), Canada as reported by (Mermut et al., 1996), Scotland as reported by (Reaves and Berrow, 1984), and Spain as

reported by (Tobias et al., 1997), to go into such research which enable them to have a central database level of trace metals concentration.

Elevated levels of trace elements are usually found in polluted or geologically interesting areas, but rare in an unpolluted soil (Davies, 1992). The soil pedologist and regulators see background data of uncontaminated soil very helpful when it comes to decision making. The reliable background data help in ensuring that the regulations are applicable for all sites, thereby, avoiding a stringent regulation that may result to unrealistic remediation project. On the other hand, regulations that are too relaxed may pose a threat to human health and the environment.

Historically, soil scientists have carried out research on trace elements and their effect on plant nutrition and their toxic nature with a good percentage of such studies conducted in the 1950's and 1960's. Tisdale et al., (1993) studied trace elements, which are regarded as nutrient in this case are required for healthy plant growth and function. They studied macronutrients (i.e., the elements require in large amounts by all plants) which include C, H, O, N, P, K, S, Ca, and Mg, although C, H, and O are not usually considered mineral nutrients (Tisdale et al., 1993). Micronutrients (i.e., those that are required by all plants in relatively smaller amounts) include Fe, Zn, Mn, Cu, B, Cl, and Mo (Tisdale et al., 1993). In addition, some micronutrients are needed by only certain plants, including Na, Co, V, Ni, and Si (Tisdale et al, 1993).

Most of the studies carried out by soil scientist are for fertility purposes with a focus on deficiencies and factors responsible for deficiencies that restrict plant growth and importance of trace elements in the life cycle of plants. In soil fertility research, variation in trace metals content of the soil has been observed. At elevated levels, some trace elements are considered

toxic to humans, plants, and animals while some of the elements are essential and required by human, plant, and animals for healthy growth and body functions.

2.3. Trace Metals as a Soil Contaminant

The widespread of trace metals emission and deposition attributed to industrial processing and agricultural purposes necessitated the special interest given to it by the international community. Trace metals such as As, Al, Cu, Cd, Fe, Ni, Hg, Pd, and Se are used in the manufacturing of some goods which in most cases elevate the naturally occurring concentrations, thereby, making them available as industrial wastes and sometimes build up in the environment. Cadmium, for example, is released into the environment by natural and human-induced activities. The natural sources of trace metals into the environment include windborne particles, biogenic emissions, and volcanoes while that of human-induced activities includes waste incineration, non-ferrous metals production, fossil fuel combustion, iron production, steel, and cement productions (Nriagu, 1989).

Cadmium is said to exist attached to particles in the atmosphere, especially the particles of submicron size such as 0.5-1 μm, Milford and Davidson (1985); Molnar et al., (1995); Pakkanen and Hillamo (2001); Allen et al., 2001; Kuloglu and Tuncel (2005); and Dillner et al., (2007). Anthropogenic sources of terrestrial Cd has been subdivided into three main categories which include: (i) agricultural application of phosphate fertilizers, (ii) atmospheric depositions, and (iii) addition of municipal sewage sludge as a replacement for phosphate fertilizers on agricultural land. There are reported cases that about 90 % of Cd usually remain in the top 15 cm of the earth's surface and the possibility of their accumulation in the soil is a factor of soil properties with clay soil proven to retain more than sandy soil (ATSDR, 1999). Cadmium exposure has been attributed to kidney and bone damage, also classified as a

potential human carcinogen, with the potential to cause cancer of the lung. In the event of long time exposure of Cd, kidney is mostly affected been one of the critical organs in the body, and all health based recommendations are related to the disturbance of the renal function.

AMAP (1998) indicated that there are various species of Cd upon emission and stated the main species as the oxides, chlorides, sulfides, and the elemental form. Anthropogenic sources emit oxides while elemental Cd is been released in such process involving high temperature; such process may include organic fossil fuel combustion and waste incineration. Coal combustion and non- ferrous metal production are the primary sources of Cd sulfides while Cd chloride comes from refuse incineration.

The fate and transport of Cd from the soil to the food-chain is being influenced by different factors, such as the plant type, soil PH, organic matter content in the soil, and zinc. The Cd available in soil is usually spread between a numbers of pools, of which the available Cd present in soil will be available for direct uptake by the plant with soil pH acting as the principal factor regulating Cd concentration in the soil solution. The Cd adsorption to soil particles is greater in neutral or alkaline soils than in acidic ones, and this leads to increased Cd levels in the solution. As a consequence, plant uptake of Cd decreases as the soil pH increases (Kabata-Pendias and Pendias, 1984).

In 1990, background concentration of Cd in Europe was documented to range between 0.2 and 1 ng/m3. By the year 2003, the concentration of Cd in the northern Europe air was 0.2-0.5 ng/m3, while that of central Europe and southern Europe was found to range between 0.06-0.12 ng/m3 in (Aas and Breivik, 2005). In 2003, Cd concentration in Europe precipitation was estimated to range between 0.03 - 0.35 µg/l while measure data on trace metals concentration became available from central Europe and Baltic Sea region. The Northern Europe recorded

concentration that range between 0.02-0.1 μg/l while the central Europe concentration range 0.04-0.2 μg/l (Aas and Breivik, 2005).

The release of lead into the environment can be from natural and artificial / anthropogenic sources. The natural occurrence of lead in the environment can be from forest fires, biogenic emissions, volcanoes, sea salt and wind suspension (Nriagu, 1989). It has been observed that emissions are not entirely natural, but contains some input from human induced activities or possibly from anthropogenic Pb that has built up into the environment over the years (Nriagu, 1989). Combustion of fossil fuel has been regarded as the major anthropogenic sources of Pb emission on a global scale, so also is the Pb emission during heavy traffic due to Pb additive in fuel, non-ferrous metal production, iron and steel production. Waste disposal and emissions during cement production has also been identified as a potential source of Pb emission (Pacyna and Pacyna, 2001). Once this Pb is released into the environment, they tend to stay in the air attached to a particulate matter and has been proven to be found with particles that range from 0.2-1.0 μm in size (Allen et al., 2001). CDC (1991), explained that Pb are usually found in the upper 2-5 cm of the soil due to their immobile nature and are not often disturbed by the organic content of the soil. Lead exposure has been established to have an adverse effect on human, such effect can be in the form of neurobehavioral effects on fetuses, infants and children, and elevate blood pressure in adults. It causes delays in neurological development, hearing loss, jaundice, and damage to renal function (ATSDR, 2005).

Similarly to Cd, Pb found in the atmosphere can travel a long distance, even thousands of kilometers and this can be attributed to the existence of Pb in the polar region, which have obviously been controlled by human induced activities for many centuries (Shotyk et al., 2005). Vestreng et al., (2005), reported that in 1990, the highest emission of Pb in Europe was

found in the road to be 80 % and dropped to 6 % in 2003. As at 2003, metal production became the highest contribution to Pb emission with a contribution of 28 %. The background concentration of Pb in air in Europe as at 1990 fall within 10-30 ng/m³ range. As at 2003, the concentrations were between 5 and 15 ng/m³ (Aas and Breivik, 2005). As at 2004, the average annual concentration in Belarus was found to be 83 ng/m³ and this value was obtained by continuous assessment of the environment and it's only possible in countries where database has been established over the year. However, the concentrations of Pb at elevated levels are always found in the city close to the industrial area (Herpin et al., 2004). In 1990, central Europe found the Pb background concentration in precipitation to be 2-5 µg/l and was found to be 1-3 µg/l in 2003 respectively (Aas and Breivik, 2005). The naturally occurring Pb in soil has been found to range between 10 mg/kg to 30 mg/kg; however, Pb is considered as a multimedia pollutant which indicate that, it comes from different sources and various factors contribute to its emission level and this makes it difficult to predict the actual sources of lead emission as such prediction always ends up in a complex pattern. Lead exposure in residential areas has been attributed to recycling activities and industrial emissions. Moreover, emissions from past industrial activities contribute to exposure through re-suspension of Pb polluted soil. Wilhelm et al., (2005), explain that Pb exposure via ingestion or inhalation always found at elevated level in the industrial area emitting Pb, be it historical or current emission.

In general, Pb exposure pathway for adults has been attributed to ingestion via food and water while that of young children and adult has been attributed to dust and the possibility of the little ones to insert materials or toys already exposure to Pb contamination (Gustavsson and Gerhardsson, 2005). The content of Pb in drinking water varies depending on country requirement and specification, for example, Svensson and German (2002), reported that

approximately 1µg/day of Pb was found in Sweden drinking water while Fertmann et al., (2004) reported an average value of 15 µg/l in Hamburg, Germany which is an area containing Pb pipes in the ancient plumbing system. The European Union set the allowable Pb content in drinking water to 25 µg/l as at 1998 and was reduced to 10 µg/l as at 2013 (EU, 1998). Lead ingestion from food materials differ from country to country depending on their allowable limit and any food exceeding the allowable limit is considered not good for consumption, For instance, The United States put their average intake by adult at 3 µg/day (JECFA, 2000), 18 µg/day in Denmark, 27 µg/day in UK (EU, 2004). JECFA (2000) and EU (2004) indicate that the dietary intake rate of Pb is higher in children than adults when compared to their body weight. Countries like Denmark have reduced their dietary intake rate to 2 µg/kg/bw/week for infant and less than 5 µg/kg/bw/week for adults.

Mercury is also available naturally in the environment at a very insignificant rate that has no negative effect to the environment or posed any form of hazard or danger. However, anthropogenic sources have greatly influenced its availability in the environment and most importantly in the soil. Geothermal activities, diffusion from the Earth mantle via lithosphere and evaporation from the sea surface has been attributed as the naturally occurring sources of Hg (Pirrone et al., 2001a, 2003) while fossil fuel combustion and coal combustion is characterized as the major sources of anthropogenic mercury. Waste disposal (open disposal), metal production, and cement production are also regarded as human induced sources of Hg emission into the environment with Au production regarded as a contributing factor to global emission of Hg (Pacyna and Pacyna, 2001; Pirrone et al., 2001a,b). Lamborg et al., (2002) estimate the naturally occurring Hg to be one-third of the total Hg in the environment with anthropogenic sources taking the remaining value. Schroeder and Munthe (1998) classified Hg

as element with a possibility of traveling over a long distance, thereby, making them available in the environment for a long time. Hedgecock and Pirrone (2004) proved that elemental gaseous Hg possesses low solubility in water, and this characteristic gives them an atmospheric lifetime of a week to several months. However, this can be seen as a contrast statement to oxidized gaseous Hg that is soluble in water with an atmospheric lifetime of a day to a few weeks. Another set of Hg is the particulate bound Hg, which is efficiently scavenged by precipitation and a short atmospheric lifetime (Hedgecock and Pirrone, 2004).

Mercury concentration in European Union countries between the year 1990 to 2003 is said to range between 1.3 ng/m³ to 2 ng/m³ (Aas and Breivik, 2005) with spatial variability of atmospheric levels of Hg considered low based on the measurement obtained from EMEP station in the European Union countries. However, Hg emission is attributed to human activities on the earth surface, thereby, indicating anthropogenic sources as the major sources of elevated Hg in the environment. The distribution of Hg in the atmosphere is usually on a global scale and usually gets to land or water surface in the form of wet or dry deposition, a factor attributed to its chemical stability. The deposition of Hg varies for each geographical location and is said to depend on the meteorological parameters of each location but in most cases evenly distributed and polar region that is a remote region is also affected.

ATSDR (1999) considered Hg as a toxic substance in either elemental or organic forms with the major concern for its organic compound such as methyl Hg with the potential possibility to accumulate in the food chain. Mercury in soil varies depending on the geographical location and activities going on in the area; however, based on the data collected from different part of the word, Hg content in soil is reported to range from 20 μg/kg to 625 μg/kg with elevated levels found mostly in urban soils. Mercury in soil has also been observed based on depth and

the outcome of the research indicate that the surface layer (i.e., the first 5 cm) contain more Hg. The European topsoil was said to contain Hg with an average value of 40 µg/kg based on 1998 measurement. The accumulation of Hg in soil has been attributed to its low mobility in soil, so also is its release into the aquatic environment which is considered a small fraction of the atmospheric input but may pose a risk to the lake ecosystem depending on the level.

The natural sources of As can be attributed to the geological materials such as rocks and soil. It has been reported to be an industrial byproduct of smelting for Cu, Pb, and Zn with an approximate emission level of about 62,000 tons per annum (Bissen and Frimmel, 2003). In 1990, the European community recorded a total emission to air of about 575 tons (Jarup, 2003). Elemental As is a naturally occurring silver-gray solid metalloid which rarely exists in nature and has low solubility and it's seldom a cause of human toxicity (Kosnett et al., 2005). However, the toxicity of As depends on its chemical composition and valency, arsine gas being the most toxic form (Ellenhorn and Barceloux, 1988) and always resulted to immediate death occurs at 150 ppm, or in 30 minutes from 25-50 ppm.

There is no doubt that trace metals pollution has impacts on our environment and human health. There have been several researches on pollution in Saudi Arabia, such research access metals content in marine, coastal, air, with limited research in topsoil. Sadiq and Zaidi (1985), examine the metals concentrations in the sediment of the Arabian Gulf coast of Saudi Arabia. Five sampling stations were selected with twenty sediment samples collected from each sampling station. Metal concentration in Manifa was found higher than other sampling locations. The obtained results were also compared with that of the United Kingdom coast, Lebanon coast, Gulf of Mexico, and Arabian Gulf of Kuwait bay. They attributed high concentration of metals in the sediment to anthropogenic sources such as petroleum and

petrochemical industries wastes and recommended continuous assessment of the marine sediment for effective environmental protection and maintenance of ecological balance.

Badr et al., (2007), also assess the levels of metals pollution in core sediment of some red sea coastal areas of Saudi Arabia. They focused their sampling to three industrialized are which include Jeddah, Rabigh, and Yambu. Their results indicate Jeddah as the most polluted, followed by Rabigh, and Yambu as the least polluted area. The soil texture in their sampling locations is silty sand with the capability to retain the metals. They recommend their studies as baseline studies for other studies that will be carried out in the area in the future.

Freije (2014), discussed metals concentration in the Arabian Gulf. His discussion was based on the review of previous studies carried out in Arabian Gulf between 1983 and 2011. He addresses issues relating to marine, coastal, soil, and air pollution in the gulf countries with his focus on marine pollution especially toxic metals and petroleum hydrocarbons. His findings on soil contamination were that of Bahrain in which indoor house dusts and outdoor street dusts was assessed. Metals content was high in the dusts, and it was attributed to emission from automobile exhaust. He recommends continuous assessment of the marine environment for effective decision making.

Al-Shayeb (2003), assessed levels of trace metals in the soils of Riyadh city. His findings reveals Pb, Zn, and Cu were at elevated levels within the city center. High Pb concentration was attributed to the emission from automobile exhaust while Zn and Cu was attributed to industrial release of substances containing such metals. His results were compared with other countries of the world such as England and Canada. He also expresses concern over elevated levels of Pb in the city center.

Adham et al (2011), assessed heavy metals pollution in Libyan jird, Meriones libycus of Riyadh city. Their results indicate that the metal concentration in the polluted soil of Riyadh city is higher than that of a reference site which is situated outside the city. They compared the result with earlier research related to soil that was carried out in the area and international standards. They reported that Pb decline compared with the early research while other metals exceeded the standard quality guidelines.

Al-Wabel and Al-Farraj, (2004) reported that some soils in Saudi Arabia are highly contaminated (Riyadh city, soils around Mah'd Aldhahab gold mine as an example). They express concern that there are no local guidelines for Saudi soils to evaluate the levels of pollution and make a right judgment. Odat and Alshammari (2011) also assessed the levels of metals in two major roads (King Abd El-Aziz and King Fahd roads) of Hail city of Saudi Arabia. The soils in the study area are moderately contaminated with respect to Cd, uncontaminated to moderately contaminated with respect to Pb, Zn, and Hg and uncontaminated with respect to Cu, Cr, Co, Ni, and V.

CHAPTER 3

METHODOLOGY

3.1 Chemicals/ Materials Used

The chemicals and materials used in this study include:

- AnalaR distilled nitric acid (HNO_3) with 69% purity, USA.
- Distilled hydrochloric acid (HCl) produced by J. T. Baker Chemicals company, USA.
- 30 % Hydrogen peroxide (H_2O_2) by UNIVAR, USA.
- Distilled water by purelab option Q, ELGA-DV 25, USA.
- CPI international standard sample, USA.
- Polythene sampling bags of size 4cm, 6cm, and 8cm.

3.2 Equipment Used

The following equipment was used during sample collection, preservation, and preparation:

- Spectro Ciros Vision Inductively Coupled Plasma - Optical Emission Spectrometry (ICP-OES)
- Auger by gilSON company, model – SP 11
- Garmin hand held global positioning system (GPS)
- Balance or scale with accuracy of 0.01g, model – Sartorius 2354
- U. S. A standard testing sieve, ASTME specification by soil test inc.
- Mechanical sieve shaker by soil test Inc., USA.
- Grinding/ crushing machine produced by rocklabs
- Filter paper - Whatman No. 41.

The pictures (Figure A1-A8) of some of the equipment used are shown in Appendix A.

3.3 Software Used

The following software was used in the preparation of the geochemical spatial distribution map:

- AutoCAD map 2010 from Autodesk.
- Surfer 8 by Golden Software Inc.
- ArcMAP 10.0 from Esri Inc.

3.4 Sampling Plan and Sample Collection

The basic motive of soil sample collection for laboratory analysis is for the collected sample to be a representative condition of the activities taking place in the sampling location. The basic procedure usually involves collection of several soil core samples over a designated area and it is expected of the soil in each sampling zone to be uniform soil types. A representative topsoil samples were collected in one hundred and thirty two (132) locations covering four (4) zones in Dammam area. The zones include residential area (denoted as R in the maps, tables, and figures throughout this thesis), industrial area (ID), agricultural area (AG), and background (BG) samples were collected in a place of no physical development. The decision of sampling position was first carried out in the office by what we called pre- planning or reconnaissance which involves having a general overview of the sample site to select sampling location. Street guide map and satellite imageries of the sample site was very useful in taking this decision as it helps in deciding the best sample points and also help in avoiding repetition in the same area. Table 3.1 shows the sample locations represented by their geographical coordinates.

Table 3.1: Locations of Collected Samples.

S/Number	Sample ID	Easting's	Northings	Depth of extraction (cm)	Observed structure	Dry/Wet
1	AG-1	399938	2936068	30	loose	Dry
2	AG-2	400161	2936683	30	Core (intact)	Wet
3	AG-3	399624	2935698	30	Core	Wet
4	AG-4	398961	2936791	30	Core	Wet
5	AG-5	400109	2935593	30	Core	Wet
6	AG-6	399639	2934789	30	Core	Wet
7	AG-7	398727	2934809	30	Core	Wet
8	AG-8	398589	2934318	30	Core	Wet
9	AG-9	400308	2935886	30	Core	Wet
10	AG-10	400308	2935999	30	Core	Wet
11	AG-11	400403	2935765	30	Core	Wet
12	AG-12	400456	2935279	30	Core	Wet
13	AG-13	400336	2934527	30	Core	Wet
14	AG-14	400729	2934096	30	Core	Wet
15	AG-15	399829	2933863	30	Core	Wet
16	AG-16	398717	2933013	30	Core	Wet
17	AG-17	399050	2931928	30	Core	Wet
18	AG-18	400755	2933705	30	Core	Wet
19	AG-19	400555	2932733	30	Core	Wet

20	AG-20	400541	2931871	30	Core	Wet
21	AG-21	399920	2931366	30	Core	Wet
22	AG-22	401620	2934630	30	Core	Wet
23	AG-23	401572	2933815	30	Core	Wet
24	AG-24	401485	2932985	30	Core	Wet
25	AG-25	401461	2932654	30	Core	Wet
26	AG-26	401563	2932263	20	Core	Wet
27	AG-27	401646	2931953	30	Core	Wet
28	AG-28	401617	2931449	30	Core	Wet
29	AG-29	397926	2936840	30	Core	Wet
30	AG-30	398259	2936319	30	Core	Wet
31	AG-31	398531	2935639	30	Core	Wet
32	AG-32	399133	2935875	30	Core	Wet
33	AG-33	3999162	2935877	20	loose	Dry
34	ID-1	413279	2920117	30	Loose	Dry
35	ID-2	413510	2919753	30	Loose	Dry
36	ID-3	413981	2919043	30	Loose	Dry
37	ID-4	413413	2918688	30	Core	Wet
38	ID-5	414990	2918449	30	Core	Wet
39	ID-6	413541	2920077	20	Loose	Dry
40	ID-7	414308	2919316	30	Loose	Dry
41	ID-8	413362	2920718	30	Loose	Dry
42	ID-9	412598	2920807	30	Loose	Dry

43	ID-10	415209	2918918	20	Loose	Dry
44	ID-11	415090	2919251	20	Core	Wet
45	ID-12	414205	2918721	30	Loose	Dry
46	ID-13	411676	2919802	30	Loose	Dry
47	ID-14	412287	2920344	30	Loose	Dry
48	ID-15	413987	2920338	30	Loose	Dry
49	ID-16	413939	2919856	30	Loose	Dry
50	ID-17	413712	2920281	30	Loose	Dry
51	ID-18	413286	2920974	30	Loose	Dry
52	ID-19	414401	2919812	30	Loose	Dry
53	ID-20	410836	2919340	15	Loose	Dry
54	ID-21	413131	2919272	30	Loose	Dry
55	ID-22	414679	2917899	20	Loose	Dry
56	ID-23	414158	2917958	30	Loose	Dry
57	ID-24	413515	2918070	30	Loose	Dry
58	ID-25	413121	2917324	30	Loose	Dry
59	ID-26	414414	2916919	30	Loose	Dry
60	ID-27	415449	2916461	30	Loose	Dry
61	ID-28	412226	2918321	30	Loose	Dry
62	ID-29	410947	2917884	30	Loose	Dry
63	ID-30	411478	2916799	30	Loose	Dry
64	ID-31	412353	2915584	30	Loose	Dry
65	ID-32	414351	2914695	30	Loose	Dry

66	ID-33	413275	2916585	30	Loose	Dry
67	R-1	406905	2925001	20	Loose	Wet
68	R-2	406928	2925147	15	Loose	Wet
69	R-3	406761	2927261	30	Core	Wet
70	R-4	408398	2925558	30	Core	Wet
71	R-5	408869	2925754	30	Core	Wet
72	R-6	408797	2924079	20	Loose	Wet
73	R-7	408896	2923351	30	Loose	Wet
74	R-8	408679	2922736	30	Core	Wet
75	R-9	409766	2922036	20	Loose	Dry
76	R-10	414484	2921179		Loose	Wet
77	R-11	406623	2926315	20	loose	Wet
78	R-12	405621	2927830	20	Loose	Wet
79	R-13	410016	2924083	20	Core	Wet
80	R-14	410646	2925874	30	Core	Wet
81	R-15	410196	2925206	20	Loose	Wet
82	R-16	410700	2925435	30	Core	Wet
83	R-17	402571	2921799	30	Loose	Dry
84	R-18	403129	2922882	30	Loose	Dry
85	R-19	403837	2925215	30	Loose	Dry
86	R-20	403919	2923126	30	Loose	Dry
87	R-21	403652	2921339	30	Loose	Dry
88	R-22	401671	2924818	30	Loose	Dry

89	R-23	415679	2920741	30	Loose	Dry
90	R-24	412200	2923100	30	Loose	Dry
91	R-25	411763	2922970	30	Loose	Dry
92	R-26	411928	2922176	30	Loose	Dry
93	R-27	412874	2921438	20	Loose	Dry
94	R-28	411384	2921347	30	Loose	Dry
95	R-29	409414	2921314	30	Loose	Dry
96	R-30	409050	2919857	30	Loose	Dry
97	R-31	410267	2921539	30	Loose	Dry
98	R-32	411039	2922027	30	Loose	Dry
99	R-33	410354	2922590	20	Loose	Dry
100	BG-1	389025	2932043	30	Loose	Dry
101	BG-2	388965	2927758	30	Loose	Dry
102	BG-3	389777	2925391	30	Loose	Dry
103	BD-4	388702	2922101	30	Loose	Dry
104	BG-5	391837	292234	30	Loose	Dry
105	BG-6	392461	2919892	30	Loose	Dry
106	BG-7	387996	2920989	30	Loose	Dry
107	BG-8	384157	2922089	30	Loose	Dry
108	BG-9	383631	2920117	30	Loose	Dry
109	BG-10	386495	2919490	30	Loose	Dry
110	BG-11	388848	2918719	30	Loose	Dry
111	BG-12	391439	2917950	30	Loose	Dry

112	BG-13	394209	2916740	30	Loose	Dry
113	BG-14	394216	2914486	30	Loose	Dry
114	BG-15	392103	2915137	30	Loose	Dry
115	BG-16	389982	2915889	30	Loose	Dry
116	BG-17	387454	2916795	30	Loose	Dry
117	BG-18	384959	2917855	30	Loose	Dry
118	BG-19	384529	2916327	30	Loose	Dry
119	BG-20	385920	2915971	30	Loose	Dry
120	BG-21	387952	2915513	30	Loose	Dry
121	BG-22	389830	2915058	30	Loose	Dry
122	BG-23	392884	2914448	30	Loose	Dry
123	BG-24	392381	2913676	30	Loose	Dry
124	BG-25	390952	2913446	30	Loose	Dry
125	BG-26	389724	2913457	30	Loose	Dry
126	BG-27	388495	2913129	30	Loose	Dry
127	BG-28	391675	2930289	30	Loose	Dry
128	BG-29	393859	2926627	30	Loose	Dry
129	BG-30	393079	2923589	30	Loose	Dry
130	BG-31	392845	2921251	30	Loose	Dry
131	BG-32	396122	2921485	30	Loose	Dry
132	BG-33	397604	2923667	30	Loose	Dry

AG: agricultural area sample; ID: industrial area sample; R: residential area sample;
BG: background sample.

The topsoil samples in the selected zones were collected with the aid of the auger and the geographical coordinates of all sample location was recorded with the aid of handheld Global Positioning System (GPS). The collected topsoil samples were stored in a polyethylene bag for transport and storage. It was air-dried naturally in the laboratory at room temperature. The air dried samples was sieved through a nylon mesh to remove large debris, stones, and pebbles.

3.5 Sieve Analysis

Sieve analysis is also referred to as gradation test. It is a set of procedure usually used to assess the particle size distribution of a granular sample. It helps in determining the relative proportion of different grain sizes according to their distribution among certain size ranges. Sieve analysis has been very useful in monitoring the quality of materials based on their particle size distribution. It is also a useful tool in the classification of soils with similar behaviours into groups and the classification can serve as a guide in determining the engineering characteristics of the soil through accumulated experience. It is also of high importance in determining the behaviour of the soil when put into use either for agricultural or construction purposes. Sieve analysis is usually adopted for sand, crushed rock, clays, granite, coal, soil, etc.

The sieve analysis procedure adopted was that of the American Association of State Highway and transportation official (AASHTO, 2006) and it's summarized below:

- The sample was dried at room temperature before the sieve analysis was carried out.
- The sample was thoroughly mixed to achieve homogeneity and a representative dried soil sample was taken and weighed.

- A stack of sieves was prepared with the large opening placed above and the smallest opening below and a pan under the smallest sieve to collect portions of soil passing through the smallest opening.
- The cleanliness of the sieve was ensured by poking the sieve with a brush when soil particles were observed stuck in the openings.
- The soil sample was poured into the stack of sieves from the top and the cover was placed. The stack of sieves was placed in the sieve shaker and clamped.
- Shaking time was set to 15 minutes and the shaker gets started.
- The shaker stopped when the set time elapsed.
- The retaining soil in each sieve was measured and recorded accordingly.

Grain size distribution can be referred to as a mathematical function that indicates the relative amount of particles present, typically by mass, according to their sizes (Jillavenkatesa et al., 2001). In order to plot the grain size distribution curve, the following formula was adopted to obtain percentage (%) weight finer.

% weight retained= 100*(weight of soil in each sieve/ total weight of the soil)

Cumulative % retained = Sum of % weight retained

% weight finer = 100-Cum % retained. % weight finer is also referred to as cumulative weight percentage passed.

The result obtained is shown in the table below which help in plotting grain size distribution curve.

Table 3.2: Agricultural Sample 1 Size Distribution.

Size(mm)	Weight(g)	% Retained	Cum % retained	% Finer
2	65.9	24.59	24.59	75.41
1	31.3	11.68	36.27	63.73
0.5	47.9	17.87	54.14	45.86
0.25	72	26.87	81.01	18.99
0.125	39.7	14.81	95.82	4.18
0.063	6.3	2.35	98.17	1.83
0.038	3.1	1.16	99.33	0.67
Pan	1.8	0.67	100	
Total	268	100		

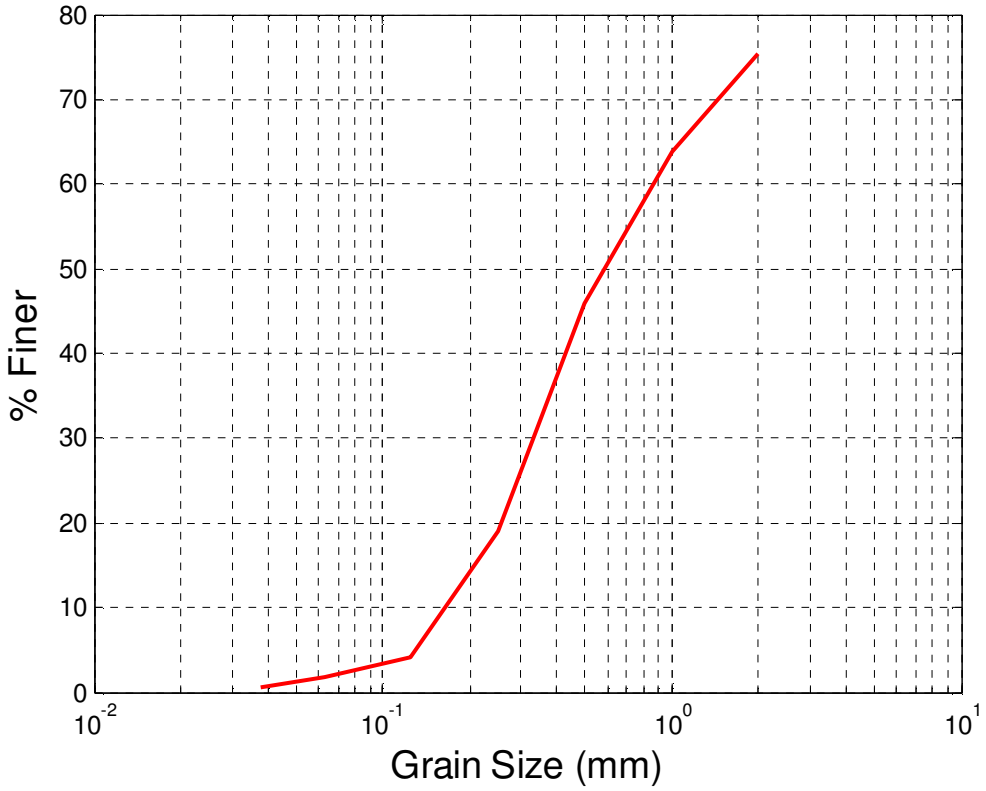

Figure 3.1: Grain Size Distribution Curve of Agricultural Sample 1.

The graph above was then used to classify the soil using unified soil classification system. In order to do this, we are going to calculate Trask sorting coefficient (TSC), coefficient of uniformity (Cu), and coefficient of curvature (Cc).

TSC $= \sqrt{(\Delta 75/\Delta 25)}$

Cu $= \Delta 60/\Delta 10$

Cc $= (\Delta 30)^2 / (\Delta 10 * \Delta 60)$

From the graph above, TSC for AG1= 2.51, Cu=5.4, and Cc=0.8. The soil is graded GP, which indicate a poorly graded sand with silt.

3.6 Criteria Used for the Soil Classification

Unified soil classification system, ASTM D2487-11 was adopted in classifying the soil. The method is based on grain size and soil consistency. Figure 3.1 was used in calculating coefficient of uniformity and coefficient of curvature. The soil id classified as coarse gravel if more than 50% of the size are gravel and coarse sand if more than 50 % of the soil is sand. The following conditions were also used in classifying the soil:

$1 < Cc < 3$ & $Cu \geq 4$ for gravel

$1 < Cc < 3$ & $Cu \geq 6$ for sand

P = poorly graded: < 5% fines, $Cu < 6$ & $1 > Cc > 3$

W = well graded: <5% fines, $Cu \geq 6$ & $1 \leq Cc \leq 3$

M = silty: > 12% fines

C = clayey: > 12% fines

3.7 ICP – OES Method of Analysis

Inductively coupled plasma - optical emission spectrometry (ICP-OES) has the capability of detecting metals and several non-metals at concentrations as low as one part in 10^{12} (part per trillion). It also possesses a greater speed, precision, and sensitivity. The wavelength characteristics of a particular element is of high priority in the use of ICP-OES as it uses inductively coupled plasma to produce excited atoms and ions that emit electromagnetic variation at such wavelength.

3.7.1 Sample preparation

The sample preparation method adopted is that of United State Environmental Protection Agency (USEPA method 3050B) for the digestion of soil, sediment, and sludge. The method is regarded as a strong acid digestion method that is capable of dissolving all elements that are environmentally available.

The equipment used for the digestion include: digestion vessels, vapor recovery device, drying oven, filter paper - Whatman No. 41 or equivalent, centrifuge and centrifuge tubes, Analytical balance - capable of accurate weighing to 0.0001g, heating source that is adjustable and has the capability to maintain a temperature of 90°C - 95°C, funnels, volumetric flash, etc. The reagent used was in conformity with the specifications of the Committee on Analytical Reagents of the American Chemical Society. Such reagents include distilled water, concentrated nitric acid (HNO_3), concentrated hydrochloric acid (HCl), and 30% hydrogen peroxide (H_2O_2). Since the digestion involves the use of acid, it was carried out in a fume hood under the supervision of expert using the approved and recommended laboratory safety equipment.

The sample preparation procedure is as stated below:

- A representative sample of 1 g fine particle soil sample was accurately measured into a 50 ml digestion tube.
- 2 ml of distilled water was put in each digestion tube to wet the sample.
- 5 ml of 1:1 HNO_3 was added to each sample and cover with a vapor recovery device.
- The sample was heated and reflux at a temperature of 95°C ± 5°C without boiling for about 15 minutes.
- The sample was then allowed to cool down before adding 5 ml of concentrated HNO_3 to each sample. The vapor recovery device which serves as cover was then replaced and the

sample was heated for 2 hours at a temperature of 95°C ± 5°C without boiling. The covering of the solution over the bottom of the vessel was ensured at all time.

- The sample was then allowed to cool down after the 2 hour heating period, 2 ml of distilled water and 3 ml of 30% H_2O_2 was then added to each of the samples in the digestion tube. Each of the samples was then covered with a vapor recovery device and returned to the heating source to enable the commencement of the peroxide reaction. The sample was heated for 2 hours at a temperature of 95°C ± 5°C without boiling. The sample was then allowed to cool down after 2 hours of boiling period.
- 5 ml of concentrated HCl was added to each of the sample and cover with the vapor recovery device. The sample was returned to heating source and heated for 15 minutes without boiling at a temperature of 95°C ± 5°C. The sample was then allowed to cool down after the heating.
- The digested sample was filtered with Whatman No. 41 filter paper and make to a volume of 50 ml.

3.7.2 ICP – OES Calibration

Multi-element standard solution was adopted for calibration of the equipment. It involves the use of six working standard samples and one blank to check the suitability and accuracy of the equipment. Table 3.3 shows the concentration of the standard samples prepared for calibration of the equipment. The calibration curve is attached to Appendix B (Figures B1 – B11).

Table 3.3: ICP-OES Standard Stock Solution.

Element	Blank	STD 1 (mg/l)	STD 2 (mg/l)	STD 3 (mg/l)	STD 4 (mg/l)	STD 5 (mg/l)	STD 6 (mg/l)	ICV (mg/l)
Al	0	0.063	0.125	0.25	0.5	1	2	0.5
As	0	0.063	0.125	0.25	0.5	1	2	0.5
B	0	0.063	0.125	0.25	0.5	1	2	0.5
Ba	0	0.031	0.062	0.125	0.25	0.5	1	0.25
Be	0	0.031	0.062	0.125	0.25	0.5	1	0.25
Bi	0	0.063	0.125	0.25	0.5	1	2	0.5
Ca	0	0.063	0.125	0.25	0.5	1	2	0.5
Cd	0	0.031	0.062	0.125	0.25	0.5	1	0.25
Co	0	0.031	0.062	0.125	0.25	0.5	1	0.25
Cr	0	0.016	0.031	0.062	0.125	0.25	0.5	0.25
Cu	0	0.063	0.125	0.25	0.5	1	2	0.5
Fe	0	0.063	0.125	0.25	0.5	1	2	0.5
Hg	0	0.016	0.031	0.062	0.125	0.25	0.5	0.25
K	0	0.156	0.312	0.625	1.25	2.5	5	1
Li	0	0.063	0.125	0.25	0.5	1	2	0.5
Mg	0	0.063	0.125	0.25	0.5	1	2	0.5
Mn	0	0.031	0.062	0.125	0.25	0.5	1	0.25
Mo	0	0.063	0.125	0.25	0.5	1	2	0.5
Na	0	0.25	0.5	1	2	4	8	4

Ni	0	0.062	0.125	0.25	0.5	1	2	0.5
P	0	0.156	0.312	0.625	1.25	2.5	5	1
Pb	0	0.062	0.125	0.25	0.5	1	2	0.5
S	0	0.156	0.312	0.625	1.25	2.5	5	5
Sb	0	0.031	0.062	0.125	0.25	0.5	1	0.5
Se	0	0.063	0.125	0.25	0.5	1	2	1
Si	0	0.156	0.312	0.625	1.25	2.5	5	2.5
Sn	0	0.031	0.062	0.125	0.25	0.5	1	0.5
Sr	0	0.063	0.125	0.25	0.5	1	2	0.5
Ti	0	0.031	0.062	0.125	0.25	0.5	1	0.5
Tl	0	0.063	0.125	0.25	0.5	1	2	0.5
V	0	0.031	0.062	0.125	0.25	0.5	1	0.25
Zn	0	0.031	0.062	0.125	0.25	0.5	1	0.25

3.7.3 Quality Assurance/Quality Control (QA/QC) Protocols

Quality control measures were adopted for each batch of processed samples. Each batch consist of 20 samples, 1 duplicate sample, 2 spiked sample, 2 blank samples, and 2 standard samples making a total of 27 samples for each set. Blank sample method was used to ascertain the possibility of the sample being contaminated. Spiked and duplicate samples were used to ascertain the precision and bias of the equipment. The results of the quality assurance / quality control (QA/QC) are attached to Appendix C.

CHAPTER 4

RESULTS AND DISCUSSIONS

This chapter deals with presentation and discussion of results. The results include grain size distribution, soil classification, and levels of trace metals in the topsoil of Dammam area.

4.1 Grain Size Distribution

The adopted sieve analysis procedure is that of the American Association of State Highway and Transportation Official (AASHTO) and the results obtained are shown below.

Table 4.1: Grain Size Distribution of Top Soil Samples Collected From Agricultural Area.

S/No	Wet (g)	Dry (g)	<38µm (g)	38µm (g)	63µm (g)	125µm (g)	250µm (g)	500µm (g)	1mm (g)	2mm (g)
AG1	282.2	269.8	1.8	3.1	6.3	39.7	72	47.9	31.3	65.9
AG 2	306.1	248.1	1.3	3.2	5.5	29.0	63.1	32.5	46.8	66.4
AG 3	235.1	218.2	1.2	2.75	5	19.6	51.3	54	42.05	42.05
AG4	280.5	243.8	0.3	3.3	7	2.4	47.7	56.2	44.8	81.6
AG5	233	223.3	1.6	3.5	7.8	1.8	23.8	37.8	32.9	113.3
AG6	263.6	246.6	0.9	3.2	8.6	11.4	52.6	57.3	63.9	48.5
AG7	241.2	213.2	0.8	3.6	15.3	16.8	71.5	52.3	32.4	20.1
AG8	236.6	207.9	1.1	4.4	11.2	38.6	63.8	56.6	20.9	10.4
AG9	313.2	279.9	2	8.5	32.5	36.2	80.4	66.2	24.1	28.9
AG10	183.2	152.7	0.75	5.4	15.4	32.5	48.6	21.3	13.6	14.9
AG11	260.1	210.8	0.38	3.1	8.9	36.4	73.2	33.4	26.4	28.6

AG12	288.4	261.8	2.5	5.5	15.6	65.9	89.8	53.8	12.8	14.9
AG13	151.4	134.9	0.8	1.6	8.9	22.8	32.4	21.7	28.6	17.9
AG14	219.7	198.3	0.2	4.7	13.3	56.6	41.7	33.5	27.3	20.7
AG15	158.3	138.4	0.3	3.6	9.7	19.7	29.7	21.4	34.5	19.4
AG16	245.5	230	0.55	9.7	22.1	29.4	84.1	33.2	21.7	28.9
AG17	189.8	168.9	0.15	1.1	8.6	19.2	69.4	22.1	27.6	20.7
AG18	211.5	178.8	0.2	4.7	11.1	22.4	62.4	26.5	33.4	17.9
AG19	255.8	245.8	0.65	3.4	7.1	32.4	88.1	57.3	34.3	22.1
AG20	231.3	212	1.3	5.55	18.7	41.6	32.5	54.6	29.9	28.1
AG21	206	181.2	0.8	5.7	11.1	22.4	63.4	26.5	33.4	17.6
AG22	248.6	188.8	0.15	4.7	15.1	24.4	64.4	26.5	33.4	19.9
AG23	192.9	156.3	1.75	6.4	15.4	33.5	48.6	22.3	13.6	14.5
AG24	211.3	174.6	0.2	4.7	11.1	22.1	60.4	24.5	33.4	17.9
AG25	197.7	160.9	1.6	8.4	15.7	34.5	48.6	21.3	15.6	14.9
AG26	206.5	167.5	0.8	7.9	18.7	37.5	49.3	22.2	14.7	16.2
AG27	192.7	173.6	0.2	4.7	9.1	21.4	62.4	26.4	33.2	15.7
AG28	226.5	197.0	1.1	5.8	16.6	25.9	65.7	25.8	35.2	20.5
AG29	285.9	249.9	0.6	11.4	25.4	31.5	87.3	35.2	24.7	33.3
AG30	204.5	182.5	0.3	5.6	10.3	24.5	63.4	25.6	34.3	18.2
AG31	233	225.6	1.8	3.7	7.8	5.8	22.2	37.5	33.6	111.7
AG32	251.1	227.7	0.3	5.6	18.3	19.8	75.5	53.3	32.4	20.1
AG33	196.2	182.8	0.5	8.4	20.4	37.5	54.6	24.3	18.6	17.9

Table 4.2: Grain Size Distribution of Top Soil Samples Collected From Industrial Area

S/No	Wet (g)	Dry (g)	<38µm (g)	38µm (g)	63µm (g)	125µm (g)	250µm (g)	500µm (g)	1mm (g)	2mm (g)
ID1	298.2	286.8	0.2	4.0	22.8	65.2	91.5	50.5	9	42.9
ID2	382.5	379.2	0.5	3.7	47.5	77.6	121.8	95	7.8	25
ID3	434.2	433.5	1.2	5.8	62.1	95.5	128.5	126.3	4.9	8.9
ID4	366.2	344.5	1.8	8.6	38.2	87.8	98.8	67.5	15.8	25.3
ID5	352.3	337.2	1.5	12.8	27.3	94.8	96.5	48.3	10.5	45.2
ID6	326.5	318.2	0.8	5.5	32.8	88.2	105.6	67.2	5.5	12.0
ID7	347.2	339.5	2.1	3.2	38.5	94.5	105.5	54.8	8.2	32.5
ID8	318.4	309.5	1.2	7.8	41.7	16.6	127.8	73.7	11.8	28.5
ID9	441.4	437.2	0.6	5.5	36	93.2	139.3	105.2	12.2	44.5
ID10	442.7	437.8	1.3	6.1	69.3	113.5	152.9	87.5	3.2	3.5
ID11	306.6	294.1	0.3	4.5	23.8	67.2	91.8	52.5	9.6	43.7
ID12	399.8	396.2	2.4	7.2	35.6	79.8	90	54.6	62.5	64
ID13	401.2	396.5	3.9	12.5	50.9	87.2	85	74	31.7	50
ID14	359.3	353.2	1.8	5.2	33.6	93.2	84.4	38.5	12.4	83.7
ID15	396.6	394.2	3.5	7.8	43.2	145.8	111.4	51.8	9.7	20.2
ID16	404.2	400.5	2.5	7.3	30.2	111.7	134.1	88.3	13.2	12.6
ID17	227.5	202.2	1.6	15.5	14.6	53.5	53	30	6	27.5
ID18	329.3	326.5	0.2	9.2	27.6	61.5	61.9	37.8	19.4	107.5
ID19	348.6	345.3	3.5	13.4	2.5	79.5	79.5	58.5	24.3	83

ID20	361.2	357.2	7.1	8.6	20.8	90.8	94.8	67.6	15.3	51.4
ID21	325.6	318	1.0	3.0	11.1	21.1	106.2	55.5	23.5	95.8
ID22	310.5	306	2.2	5.1	6.2	66.5	57.9	45.3	32.4	90.1
ID23	399.9	394	4.0	4.5	41.8	90.8	95.9	61.3	18.2	77.2
ID24	331.3	325.4	1.0	6.8	11.6	55.1	41	31.8	28.2	148.2
ID25	292.4	289	1.2	7.8	41.7	16.6	110.8	71.7	11.8	28.5
ID26	436.5	431.7	2.2	3.2	71.3	115	130.4	90.4	14.6	4
ID27	375.6	370	1.8	15.2	38.6	95.2	84.4	38.5	12.4	83.1
ID28	432.2	431.7	1.5	30.5	66.8	60.3	105.5	83	38	45
ID29	481.4	475.3	2.2	3.9	87.9	194.3	143.5	37.8	3.4	1
ID30	445.5	443.5	1.6	10.8	54.1	187.6	80.20	27.5	15.8	65
ID31	451.4	445.8	0.8	4.8	55	93.3	138	92.9	55	5.5
ID32	389.2	387.6	0.6	6.9	54.2	108.6	101.1	91.6	12.2	11.5
ID33	296.7	289.2	0.3	4.1	22.9	65.7	92.3	50.5	9.4	43.4

Table 4.3: Grain Size Distribution of Top Soil Samples Collected From Residential Area.

S/No	Wet (g)	Dry (g)	<38µm (g)	38µm (g)	63µm (g)	125µm (g)	250µm (g)	500µm (g)	1mm (g)	2mm (g)
R1	176	153.9	0.00	2.6	6.8	11.4	15.6	50.4	26.2	40
R2	235.1	200.7	0.6	5.4	30	33.2	19.4	50	28.6	40.5
R3	201.4	187.2	0.1	1.75	3.5	19.6	41.3	54	33.7	32.5
R4	195.7	177.8	0.8	2.4	10.2	28.6	61.6	46.6	15.9	10.4
R5	129.5	119.7	0.3	3.9	12.4	27.5	44.8	14.3	8.6	7.9
R6	120.2	114.4	0.3	3.6	17.6	29.1	23.3	26.1	7.3	5.8
R7	156.6	152.8	1.2	7.3	20.2	53.1	31.5	17.2	7.3	4.3
R8	136.5	130.7	0.4	2.6	15.4	21.4	35.3	30.4	16.2	8.4
R9	129.1	120.3	0.25	3.7	11.8	26.9	47.6	13.3	9.3	6.8
R10	130.6	118.6	0.3	2.8	13.5	23.6	42.1	18.4	11.5	5.6
R11	119.2	116.2	0.5	1.9	8.7	19.1	47.6	20.2	8.3	9.4
R12	123.4	115.5	1.7	2.4	18.2	28.4	21.3	25.2	8.7	8.5
R13	135.3	129.3	0.8	3.8	10.7	16.6	55.8	21.7	5.8	13.5
R14	164	162.1	1.1	8.9	21.2	59.6	37.4	17.2	10.2	5.7
R15	151	123.8	0.6	4.1	12.4	27.5	48.6	13.6	7.6	8.7
R16	124.6	124.2	0.7	2.8	14.6	19.9	33.4	26.5	16.3	9.2
R17	162.9	161.2	1.2	9.3	19.6	63.2	34.5	16.7	9.6	6.3
R18	126	122.15	0.55	3.9	18.3	30.6	24.2	28.4	8.4	6.8
R19	153	152.2	0.4	11.2	20.6	53.3	32.6	14.3	11.7	7.85

R20	160.6	158.2	1.53	5.7	13.6	17.5	19.4	47.4	25.8	26.8
R21	148.9	148.3	0.8	3.6	17.4	27.4	38.3	32.4	18.2	9.4
R22	138	133.2	1.25	5.43	15.2	21.7	36.8	25.5	17.9	8.5
R23	118	112.8	0.44	6.2	16.1	31.3	21.6	19.9	10.3	6.8
R24	122.5	116.7	0.67	2.9	7.5	18.6	46.6	22.6	9.4	7.6
R25	133.61	130.8	0.55	3.3	11.9	22.05	36.1	28.5	17.3	10.7
R26	168.9	167.4	0.7	8.5	25.4	55.4	32.9	17.8	14.4	11.6
R27	150.9	147.5	1.1	5.3	19.6	39.8	29.7	26.8	15.4	9.3
R28	148.5	147.9	0.4	6.2	14.7	23.7	43.6	29.9	19.8	8.9
R29	149.1	147.8	0.75	4.5	23.8	42.2	31.8	23.5	6.6	13.7
R30	149.3	146.8	1.6	8.8	18.5	48.4	35.5	15.8	6.9	10.6
R31	146.2	145	0.95	5.3	15.6	25.7	37.3	28.4	11.6	19.5
R32	140.3	140.1	0.8	7.5	13.2	33.3	32.6	21.6	15.9	14.3
R33	177.5	174.3	1.3	10.3	27.8	53.7	31.3	21.2	16.7	21.6

Table 4.4: Grain Size Distribution of Top Soil Samples Collected From Background Area.

S/No	Wet (g)	Dry (g)	<38µm (g)	38µm (g)	63µm (g)	125µm (g)	250µm (g)	500µm (g)	1mm (g)	2mm (g)
BG1	332.6	328.9	1.8	3.9	25.4	140.1	127	21.9	5.1	3.2
BG2	313.4	303.6	1.0	7.6	27.6	128.1	101.3	22.1	12.3	2.9
BG3	381.3	378.5	2.1	12.3	29.8	157.6	133.2	31.5	6.4	4.1
BG4	322.6	317.8	0.7	2.8	23.9	136.2	118.3	22.4	7.4	5.2
BG5	373.4	361.1	2.6	4.3	28.4	153.9	131.6	26.7	9.1	3.7
BG6	322.5	313.7	1.3	7.1	22.9	115.7	91.3	51.5	19.4	3.4
BG7	320.8	316.2	0.8	11.1	18.5	103.7	97.8	49.2	25.7	8.6
BG8	331.4	327.5	1.5	9.3	27.7	138.1	81.7	56.0	8.5	4.7
BG9	363.5	352.9	1.1	13.7	23.2	142.4	100.3	44.7	17.3	9.3
BG10	377.8	366.7	0.9	4.9	37.2	127.9	99.3	78.2	9.3	8.4
BG11	314.6	304.8	1.2	15.2	38.6	105.2	84.4	38.5	12.4	8.1
BG12	318.3	309.6	0.2	3.7	39.7	128.3	78.9	29.8	18.6	10.2
BG13	327.9	322.2	3.2	14.2	43.1	107.9	81.7	35.6	19.2	16.3
BG14	326.4	321.8	0.9	11.4	39.4	113.3	92.1	43.6	13.7	5.9
BG15	324.7	321.2	2.6	18.5	29.7	121.7	94.4	28.4	17.6	7.9
BG16	311.5	305.5	1.6	15.5	18.6	153.5	63	30.7	13.6	7.5
BG17	321.8	316.2	1.3	13.2	25.7	128.4	86.4	28.6	17.2	13.7
BG18	328.6	325.2	3.1	12.3	27.8	137.6	103.2	27.5	8.4	4.1
BG19	327.2	322.7	0.9	3.8	26.5	121.3	89.3	57.3	19.4	3.4

BG20	316.7	309.5	2.7	17.3	38.6	133.2	61.5	27.7	18.6	9.3
BG21	362.4	355.5	2.2	9.3	53.2	109.2	89.4	72.6	11.8	6.9
BG22	332.6	326.2	0.8	7.7	32.2	115.9	83.6	59.8	17.3	8.4
BG23	335.3	331.8	1.3	11.3	47.3	104.4	79.7	63.4	14.2	9.4
BG24	319.7	314.1	1.6	4.9	29.4	114.1	107	27.9	15.1	13.2
BG25	331.9	326.9	1.7	15.2	27.5	118.4	86.7	48.6	17.2	10.9
BG26	349.6	347.5	1.2	8.8	47.4	116.6	87.8	54.3	21.9	8.5
BG27	312.5	307.2	0.7	9.7	31.4	119.7	78.4	39.5	18.3	9.2
BG28	316.4	309.4	0.5	10.3	27.8	113.7	81.3	41.2	21.7	11.6
BG29	337.5	333.5	1.3	11.1	23.4	122.4	90.3	47.7	27.3	9.3
BG30	338.3	334.2	1.2	17.2	38.6	109.2	88.5	38.3	22.4	18.1
BG31	346.3	339.5	0.2	6.0	22.8	125.2	91.5	50.5	29	12.9
BG32	323.6	317.3	0.6	14.2	29.4	104.1	87.6	47.9	19.3	13.6
BG33	328.6	321.2	0.9	8.8	43.2	116.5	73.4	52.7	15.5	9.1

4.2 Classification of Soil Samples Collected

Classification of soil types is based on grain size distribution and soil consistencies. It provides an avenue through which research related to soil can be addressed in a rigorously systematic manner. Unified soil classification system was adopted in classifying the soil. Table 4.5 shows the extract of some of the samples and their corresponding soil type.

Table 4.5: Soil Type in the Selected Sampling Location.

Sample Id	**Soil types**
AG-1	Poorly graded sand with silt
AG-2	Poorly graded sand with gravel
AG-10	Silty sand
AG-15	Poorly graded sand with silt
AG-20	Poorly graded sand with silt
AG-26	Silty sand
AG-33	Silty sand
ID-1	Silty sand
ID-4	Silty sand
ID-8	Silty sand
ID-12	Poorly graded sand with silt and gravel
ID-13	Silty sand
ID-14	Poorly graded sand with silt and gravel
ID-15	Silty sand
ID-17	Silty sand
ID-18	Poorly graded sand with silt and gravel

ID-30	Silty sand
ID- 33	Poorly graded sand with silt and clay
R-1	Well graded sand with silt and gravel
R-5	Poorly graded sand
R-6	Silty sand
R-12	Poorly graded sand with silt
R-17	Poorly graded sand with silt.
R-18	Silty sand
R-24	Poorly graded sand
R-33	Silty sand
BG-16	Poorly graded sand with silt
BG-1	Poorly graded sand with silt
BG-4	Poorly graded sand with silt
BG- 32	Silty sand
BG-15	Silty sand

4.3 Trace Metals Levels in the Topsoil of Dammam Area

The trace metals levels in the topsoil of Dammam Area are summarized in Tables 4.6 to Table 4.9 below for the different zones while the tabulated data is listed in Appendix D. The summary of the data include the mean and standard deviation of each element under investigation for each zone.

Table 4.6: Trace Metals Levels in Agricultural Area.

Elements	Range(mg/kg)	Mean (mg/kg)	Std. deviation (mg/kg)
As	0.40-3.10	1.51	0.64
Ba	7.80-100.65	34.45	19.62
Cd	0-1.14	0.06	0.19
Cr	3.03-66.80	24.44	16.66
Cu	0.97-16.17	8.73	6.96
Hg	0-1.20	0.08	0.20
Ni	4.6-16.25	9.22	2.61
Pb	0.9-52.35	6.49	8.84
Ti	0.075-160.50	101.53	57.93
V	1.6-21.60	11.52	6.33
Zn	1.01-42.70	12.43	9.10

Table 4.7: Trace Metals Levels in Industrial Area.

Elements	Range(mg/kg)	Mean (mg/kg)	Std. deviation (mg/kg)
As	0.75-4.50	1.57	0.85
Ba	0-1966	335.35	447.65
Cd	0-28.60	1.87	5.85
Cr	0.12-247	51.77	62.59
Cu	0.18-95.70	10.99	22.45
Hg	0-1.40	0.11	0.26
Ni	5.5-45.10	13.14	8.79
Pb	0.4-100.20	11.42	25.75
Ti	1.64-311.80	188.51	109.28
V	0.08-20.40	13.11	5.94
Zn	0.09-676	65.44	159.28

Table 4.8: Trace Metals Levels in Residential Samples.

Elements	Range(mg/kg)	Mean (mg/kg)	Std. deviation (mg/kg)
As	0.1-1.70	0.97	0.38
Ba	0.33-98.50	34.10	26.92
Cd	0-23	1.87	4.67
Cr	0.07-120	29.63	28.85
Cu	0.04-19.10	4.38	4.35
Hg	0-0.50	0.05	0.10
Ni	2.2-13.20	6.44	2.46
Pb	0.08-18.60	4.79	6.27
Ti	1.08-232.80	85.87	57.86
V	0.07-17.70	7.01	4.95
Zn	0-39.30	8.46	9.48

Table 4.9: Trace Metals Levels in Background Samples.

Elements	Range(mg/kg)	Mean (mg/kg)	Std. deviation (mg/kg)
As	0.38-1.50	0.69	0.26
Ba	0.4-43.50	25.67	13.83
Cd	0-0.20	0.04	0.07
Cr	0.1-28.20	19.44	6.43
Cu	0.1-3.90	2.24	1.40
Hg	0-0.10	0.034	0.03
Ni	1.7-16.30	6.64	2.80
Pb	0.6-14.90	2.01	2.94
Ti	1.1-359	97.93	64.21
V	0.06-12.50	7.95	4.89
Zn	0.03-32.90	4.57	6.44

4.4 Geochemical Spatial Distribution Map

The AutoCAD software was used to produce the geochemical map of the sample locations. The sample locations recorded with handheld GPS during sample collection were downloaded using Microsoft excel and saved in (csv) format. A project was created in AutoCAD and all necessary settings (such as units, angles, format, coordinates, origin, etc.) were applied. The sample locations coordinates were then imported into the AutoCAD and were superimposed on the map of Dammam area. The sample location drawing is attached in Figure 4.1.

Surfer 8 software was then used to produce the geochemical spatial distribution map of each element detected in different locations. The geographical coordinates of each sample location recorded during sample collection was used together with the trace metal concentration in each location after analysis.

The data was arranged in E, N, and Z format with E meaning easting, N means Northing, and Z represents the concentration of each of the trace metals under investigation in mg/kg. The data was prepared for each of the eleven (11) elements under investigation.

ArcGIS 10.0 version was used for overlay of each element under investigation on the satellite imageries of the area.

The overlay map of each of the elements are shown in Figure 4.2 to Figure 4.12.

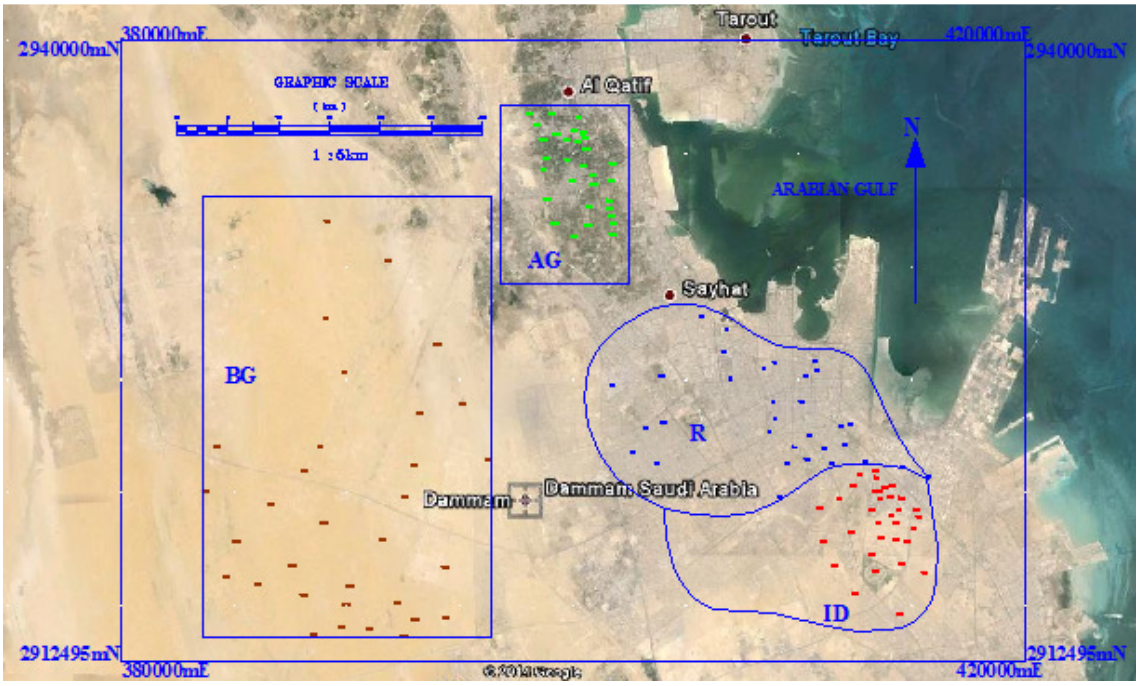

Figure 4.1 The Sample Locations in Dammam Area

NOTE: Agricultural area in green dot, residential area in blue dot, industrial area in red dot, and background samples in brown dots.

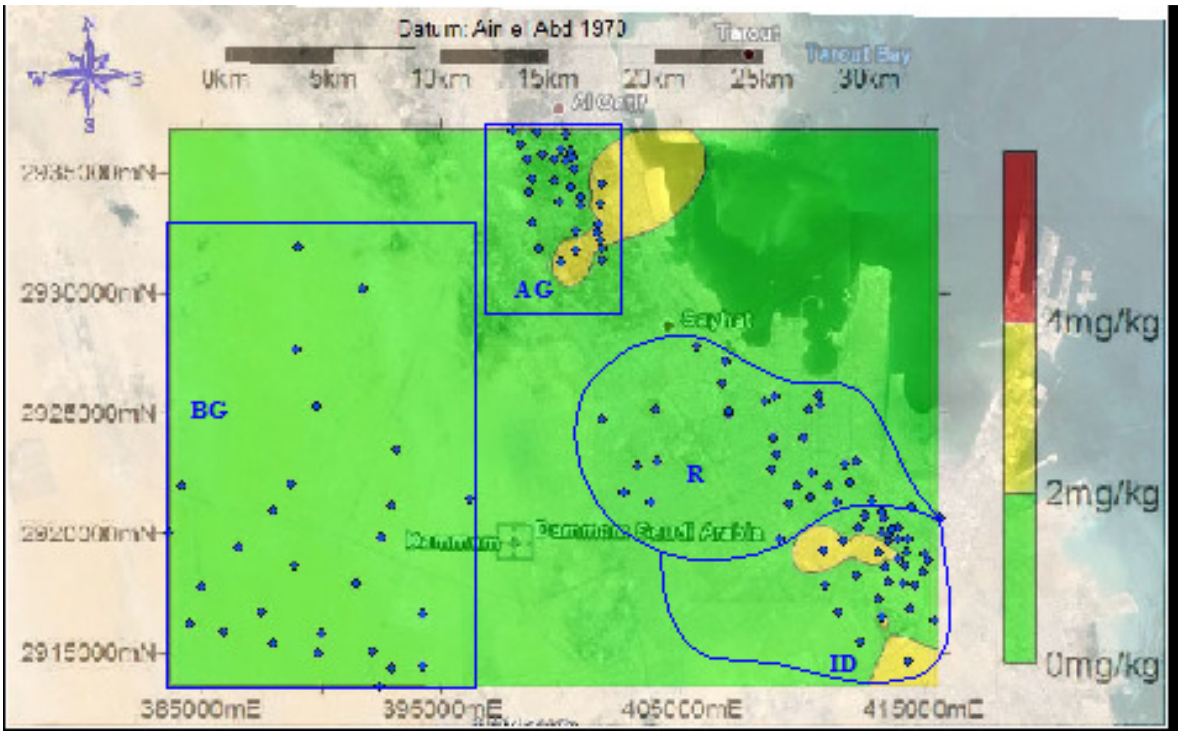

Figure 4.2 Spatial Distribution of Arsenic Concentrations.

The vertical bar at the right side of the plot shows the concentration scale.

Arsenic is an element of the earth's crust that exists naturally in the environment. The naturally occurring pathways of exposure include, but are not limited to volcanic ash, weathering of As-containing minerals and ores, and dissolved in groundwater. It is also found in food, water, soil, and air (ATSDR, 2010). Arsenic is absorbed by all plants, but is more concentrated in leafy vegetables, rice, apple and grape juice, and seafood. An additional route of exposure is through inhalation (ATSDR, 2009). It has the capability of combining with other elements such as S, O, and Cl to form inorganic As compounds. Exposure to high levels of As usually occurs in workplaces close to hazardous waste site or in areas with naturally occurring As either in soil, water or rock materials. USOSHA (2007) states that exposure to high levels of As can result in death and exposure to low levels of As for an extended period of time can result to discoloration of the skin and appearance of small corns or warts.

The availability of As in the environment may also be attributed to its use in the production of pesticides, herbicides, insecticides, and treated wood products. However, its use is declining because of its toxic nature when it exceeds the allowable standard for the environment (Sabina et al., 2005). Arsenic is notoriously poisonous to multi-cellular life, although a few species of bacteria are able to use As compounds as respiratory metabolites. Emsley (2011) explains the abundance of As in the environment by giving its values to be 1.5 ppm (0.00015 %) in the Earth's crust which makes it 53rd most abundant element. He also states that soil contains 1-10 ppm of As and seawater with only 1.6 ppb. An increased appreciation of the toxicity of As resulted in a ban for the use of chromated copper arsenate (CCA) in consumer products; the European Union and United States initiated this process in 2004 (Mandal and Suzuki, 2002; Lichtfouse, 2004). CCA remains in heavy use in other countries, e.g. Malaysian rubber plantations (Sabina et al., 2005).

Based on the result obtained from our analysis, it was observed that As was found in abundance in agricultural area than all other sampling locations. This result may be attributed to the use

of As in various agricultural insecticides and poisons. For example, lead hydrogen arsenate as a common insecticide on fruit trees (Peryea, 1998). However, efforts are being made by different country of the world to replace organic As with less toxic organic forms of As such as monosodium methyl arsenate and disodium methyl arsenate (Nachman et al., 2005). Another valid reason for high levels of As in agricultural areas can also be attributed to the use of As as feed additive in poultry and swine production, to increase weight gain, improve feed efficiency, and to prevent disease (Nachman et al., 2005). Roxarsone is an example of feed additives that has been used by poultry farmers; however, the poison free poultry act 2009 proposed to ban the use of roxarsone in industrial swine and poultry production.

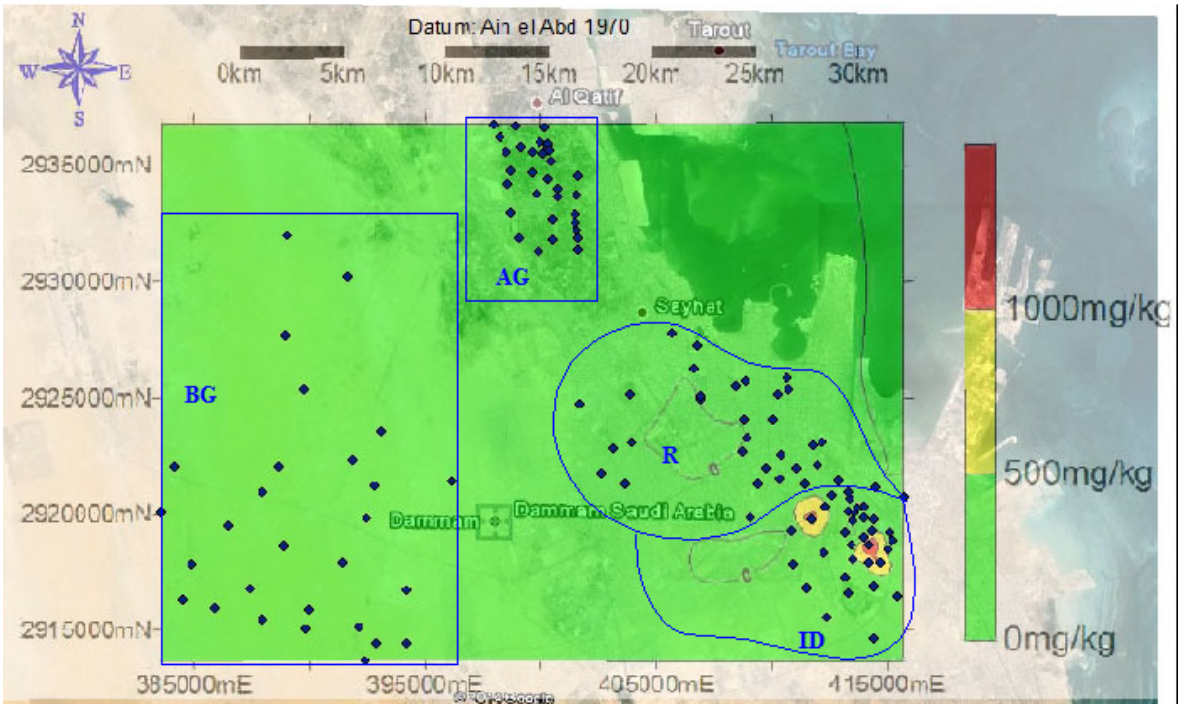

Figure 4.3 Spatial Distribution of Barium Concentrations.

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Barium possesses a high chemical reactivity and has never been found as a free element in nature. Barite is insoluble in water and it is regarded as the most common naturally occurring minerals. The earth's crust consists of 0.0425 % of Ba while 13 µg/L of Ba can be found in the seawater (Kresse et al., 2007). Barium possesses a low vapor pressure and high reactivity with oxygen, nitrogen, carbon dioxide, and this characteristic is responsible for its ability to remove unwanted gases from vacuum tubes such as TV picture tubes. However, the adoption of Ba for this purpose is reducing due to the emergence of tubeless LCD TV and plasma sets (Kresse et al., 2007).

Some compound of Ba such as barium sulfate ($BaSO_4$) found application in petroleum related industry, especially as a drilling fluid in oil and gas wells (Lide, 2004). It also finds application as a paper coating pigment and can also be used to improve the physical properties of some polymers such as epoxies (Kresse et al., 2007).

The results from the collected samples indicate high levels of Ba in some of the industrial samples. Since there are no guidelines regarding the allowable limit of barium expected to be found in the soil in the project area, Canadian Environmental Guidelines for the Protection of Environment and Human Health was adopted. The guidelines stated that the concentration of Ba in agricultural area should not exceed 750 mg/kg, residential area with 500 mg/kg while that of industrial area should not exceed 2000 mg/kg. The result obtained for agricultural, background and residential area falls within the allowable range except for industrial areas that shows elevated levels of Ba. The elevated levels in industrial areas can be attributed to the use of Ba compound or oxides for various industrial activities in the area.

Industrial application of Ba include, but are not limited to the use of Ba - oxide as coating for the electrodes of fluorescent lamps; the use of Ba-carbonate in glassmaking which increases the refractive index of the glass (Lide, 2004); the use of Ba compound to minimize leaks of X-

rays from cathode ray tubes (Kresse et al., 2007); the use of Ba nitrate in fireworks to give them a green color (Russell and Svrcula, 2008); and the use of Ba titanate as a promising electro-ceramics (Wadhawan, 2000). The above named industrial activities may be responsible for elevated levels of Ba in the sampling location.

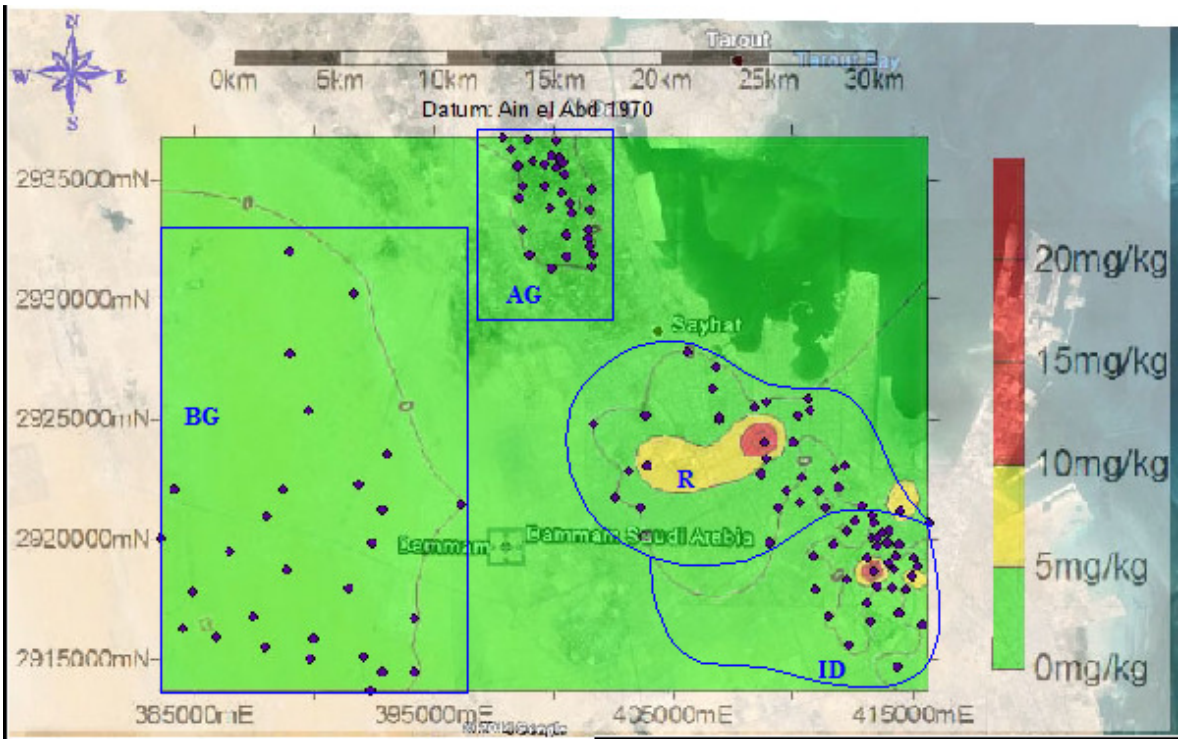

Figure 4.4 Spatial Distribution of Cadmium Concentrations.

The occurrence of Cd in the earth's crust was estimated to be 0.1 ppm (Wedepohl, 1995). Its usefulness in industries such as its presence in the production of battery (Buxbaum and Pfaff, 2005), coatings (Smith et al., 1999), and electroplating (Scoullos et al., 2001) makes it available in the environment and may contribute to its elevated levels. Oxides of Cd also find application in the production of television (Lee and Hsi, 2002), a factor that may be responsible for elevated levels of Cd if proper regulations and monitoring are not put in place. Morrow (2010), considered inhalation of fine dust/ fumes and ingestion of highly soluble Cd compound as the most harmful form of occupation exposure, which can result to metal fume fever and can also result to pulmonary edema and even death in some cases (Hayes, 2007).

The results from the analysis indicates the levels of Cd in agricultural area to be within the allowable limit expected to be in the soil where agricultural activities are taken place. The results for background samples, residential samples, and industrial samples also falls within the allowable limit except for sample 6 in residential samples, and sample 4 in industrial samples that exceeded the allowable limit. The elevated level of Cd in industrial sample 4 can be attributed to various industrial activities in the area and can also be as a result of atmospheric deposition or illegal / accidental dumping of material containing Cd.

It is worthy of note to remember that Cd can get into the environment via fossil fuel combustion, phosphate fertilizers, iron and steel production, cement production, and municipal solid waste incineration (Morrow, 2010). The IARC has classified Cd as carcinogenic to humans. Although occupational exposure to Cd is linked to lung and prostate cancer, there is still a substantial controversy about the carcinogenicity of Cd in environmental exposure.

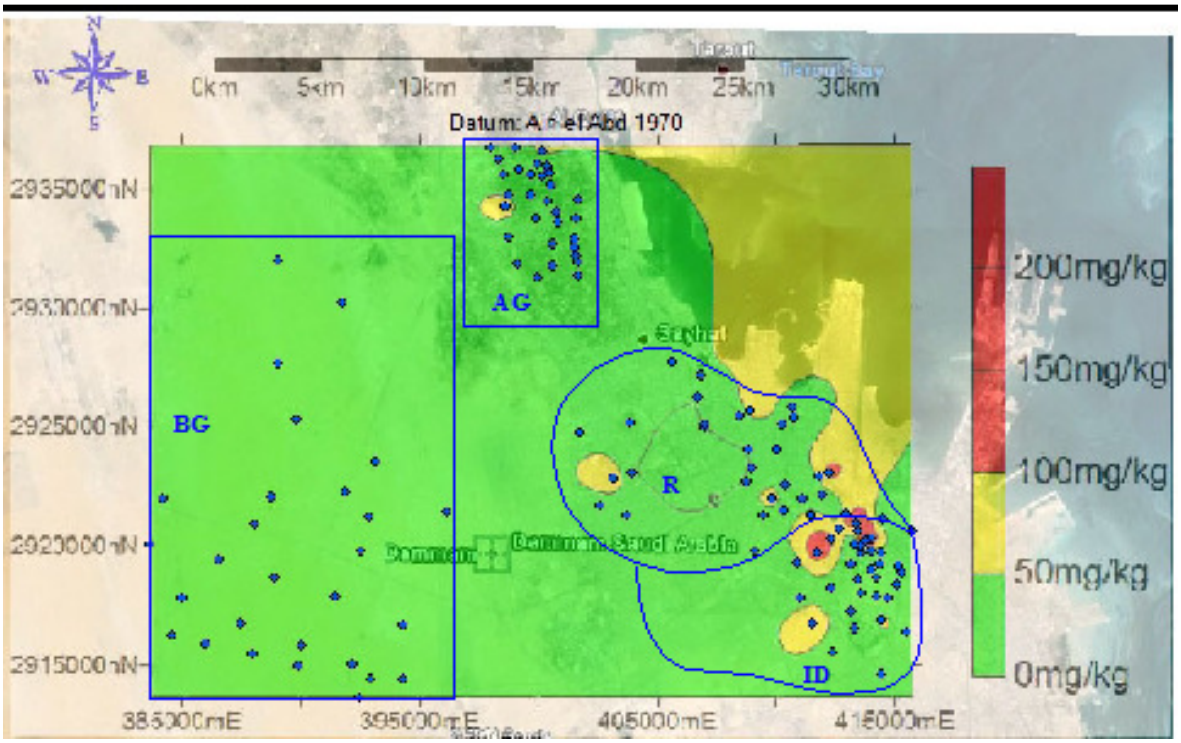

Figure 4.5 Spatial Distribution of Chromium Concentrations.

Emsley (2011) regarded Cr as the 22nd most abundant element in the earth's crust with an average concentration of 100 ppm. Its availability in the environment can be attributed to the breaking down of rock material containing Cr which can be distributed by volcanic eruptions (Kotas and Stasicka, 2000). In most cases, elevated levels of Cr are found in abandoned industrial sites, a factor that can be attributed to its use in dyes, paints and tanning of leather (Baselt, 2008). The toxicity of Cr is also of great importance in wood preservation as it protects the wood from wood attacking insects such as termites and marine borers (Hingston, 2001). It also found application in cleaning laboratory glassware of any trace of organic compound due to its ability as a powerful oxidizing agent. However, proper care must be taken in the use of Cr or its compound to avoid unnecessary release of Cr containing compounds into the environment.

The result obtained indicate levels of Cr in background samples to fall within the allowable limit permitted to be present in soil while that of agricultural area also falls within the permissible limit except for agricultural sample 2 that exceeded the allowable limit permissible in agricultural soil. The elevated levels in one of the agricultural soil samples may be attributed to either natural source or atmospheric deposition of Cr containing compound. The residential soil samples show elevated levels of Cr in samples 5, 18, and 24, a factor that can be attributed to either its use as wood preservation, accidental release or atmospheric deposition of Cr containing compound. Industrial samples 13, 14, 15, 17, 18, and 30 also shows elevated levels of Cr which can be attributed to the use of Cr containing compound for industrial application such as its use in dyes, paints, and tanning of leathers.

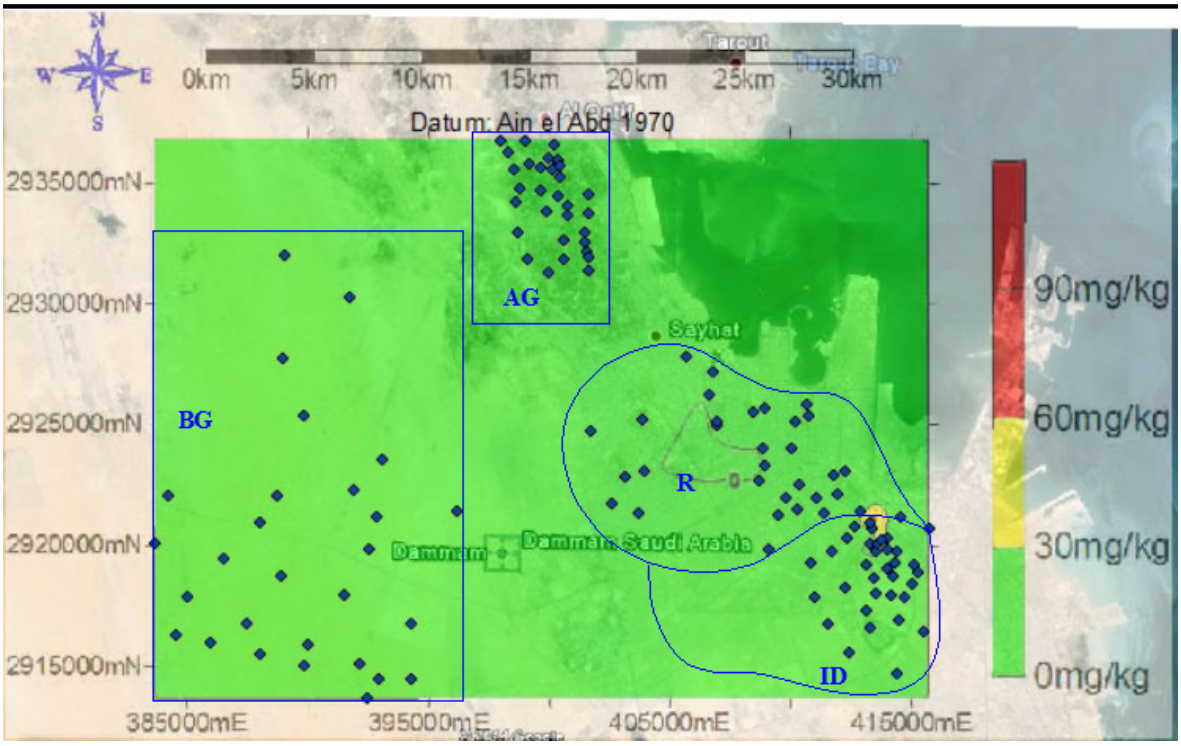

Figure 4.6 Spatial Distribution of Copper Concentrations.

Copper is an essential part of respiratory enzymes in living organisms usually require at a very small amount by the body and found in liver, muscle, and bones in humans (Johnson, 2008). It is found naturally in the earth's crust at about 50 ppm (Emsley, 2003). Cu and Al are 100 % recyclable without any loss of quality, regardless of whether they are in a raw state or contained in a manufactured product. The American Conference of Governmental Industrial Hygienist (ACEIH) stated 1 mg / m^3 as occupational exposure limit while Canadian Guidelines for the Protection of Environment and Human Health (CGPEHH) stated 64 mg/kg for agricultural soil, 87 mg/kg for industrial soil samples, and 64 mg/kg for residential soil samples.

Considering the results obtained from the analysis of soil samples collected, the concentration of Cu in all the samples were within the allowable limit except for industrial samples 17 and 18 that are above the stated limit. The elevated levels of Cu in two out of 33 industrial samples may be attributed to the industrial activities in the area since Cu finds application in the production of electrical wires, roofing, plumbing, and industrial machinery (Emsley, 2003). It can also be as a result of atmospheric deposition or accidental release of a Cu containing compound. However, ample care must be exercised when dealing with Cu or Cu containing compound to reduce human exposure to it.

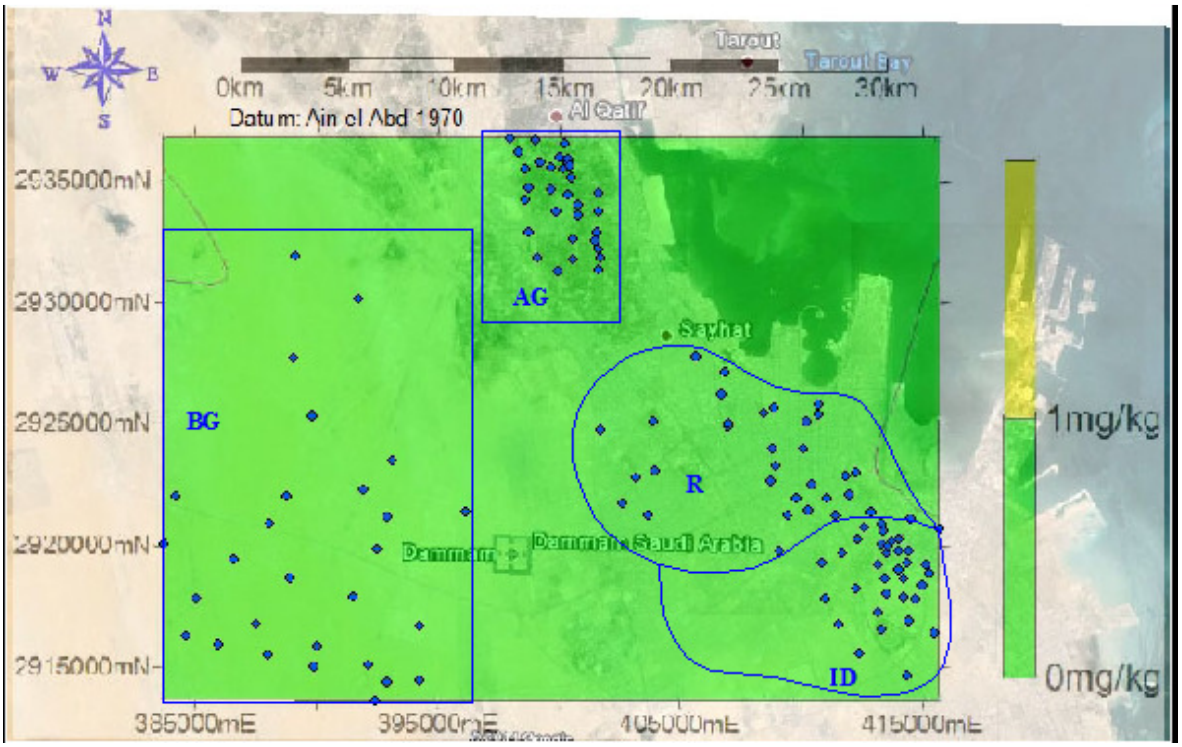

Figure 4.7 Spatial Distribution of Mercury Concentrations.

The mode of entry of Hg or Hg containing compound is through inhalation, ingestion, and absorption through skin with 0.025 mg / m^3 total weight average as specified by ACGIH. The Canadian Environmental Soil Quality Guidelines for the Protection of Environment and Human Health specify 6.6 mg/kg as the maximum amount of Hg expected to be in agricultural and residential soil area while that of industrial area should not exceed 50 mg/kg. The toxic effects of Hg when this limit is exceeded may include allergic reaction, damage to the lungs, brain, and kidney (Clifton, 2007). However, the obtained results of all the samples analyzed for Hg indicates that Hg levels in all the samples are within the allowable limit as specified by the adopted specifications.

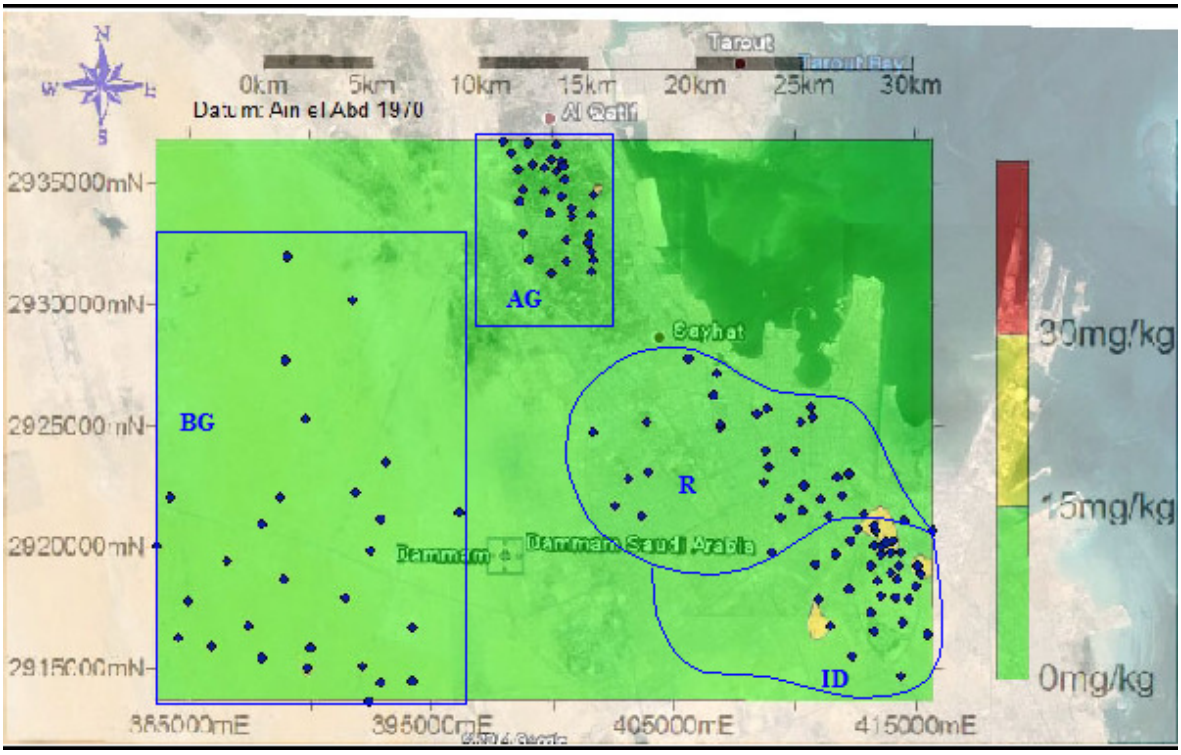

Figure 4.8 Spatial Distribution of Nickel Concentrations.

Nickel is an essential element for human nutrition that exists naturally in the environment at low concentration (USEPA, 1999). The release of the Ni containing compound from oil and gas combustion, sewage sludge incineration, and manufacturing activities that involved the use or release of Ni containing compounds are responsible for the presence of Ni in ambient air. The USEPA specify 1000 µg/day as a dietary limit of Ni (Trumbo et al., 2001) with an average ingestion limit of 69-162 µg/day (ATSDR, 2005). In the case of elevated level of Ni in human, severe damage to the lungs and kidneys, gastrointestinal distress such as vomiting, pulmonary fibrosis, and renal edema has been reported (ATSDR, 1997). However, the level of Ni in the analyzed samples is within the allowable range as specified by the adopted specification.

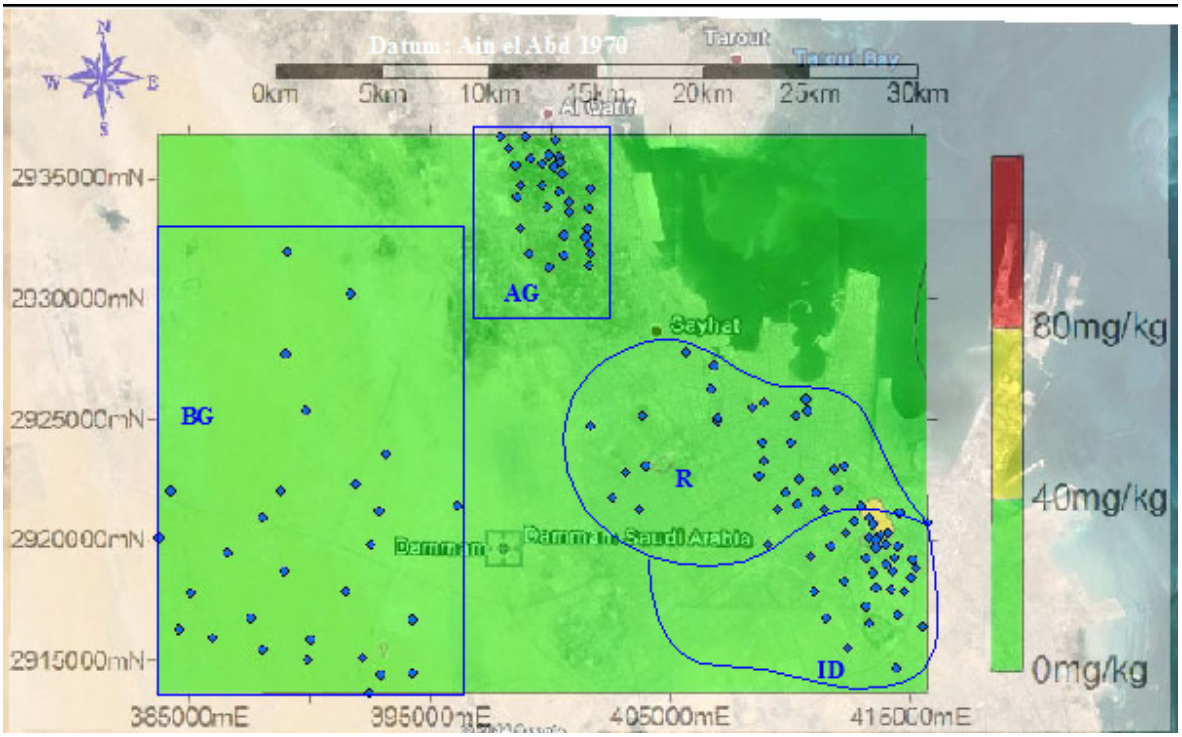

Figure 4.9 Spatial Distribution of Lead Concentrations.

Lead occurs naturally in the environment at a very small amount. Its physiological role in the human body cannot be ascertained, but found application in the production of paints, plumbing materials, batteries, etc., and its harmful effects are diverse (Manay et al., 2008). Pb in its natural form has no health effect, but human activities on the earth's surface such as leaded gasoline, fossil fuels are responsible for the elevated levels of Pb in the environment. Guidotti and Ragain (2007) express concern about the possibility of Pb residual in soil to elevate its levels in the environment. Barltrop et al., (1975) also explain that the level of pollution in the environment with different contaminants will possibly increase the level of Pb in the environment. Although, there is no specification regarding the level of Pb expected to be found in Dammam soil, all samples analyzed fall within the allowable range of the adopted specification. However, ample care and proper monitoring of the soil and the environment should be a continuous process.

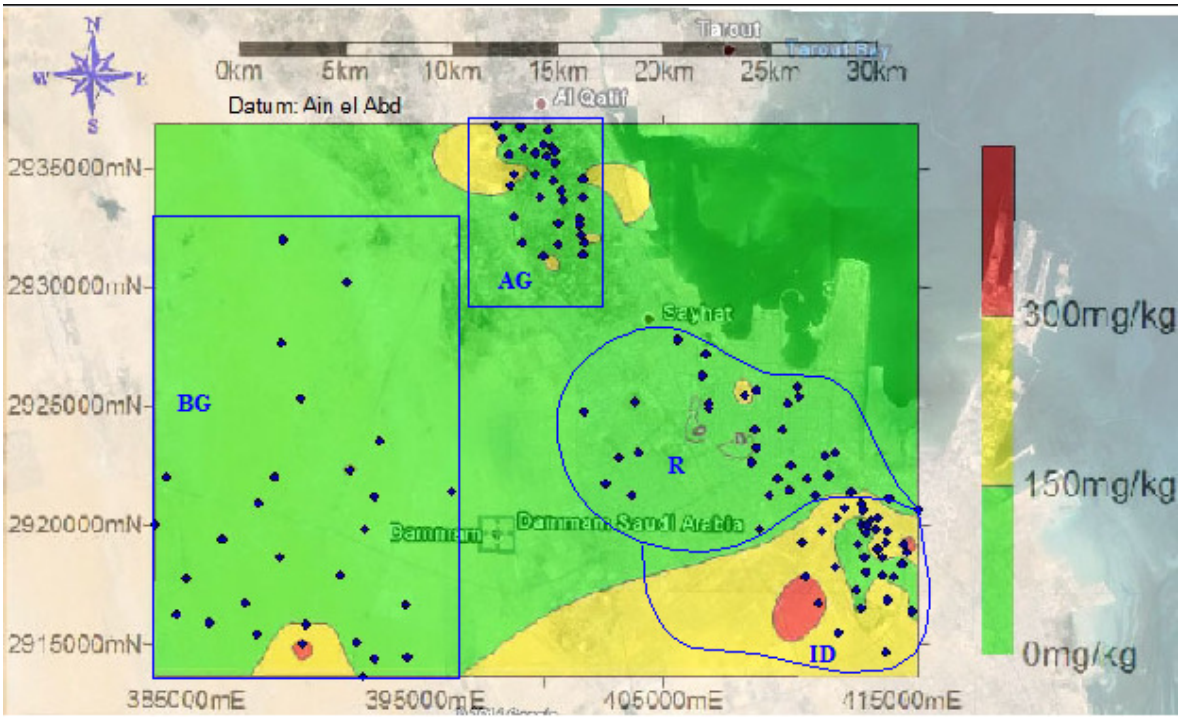

Figure 4.10 Spatial Distribution of Titanium Concentrations.

Titanium occurs naturally in the earth's crust, especially in igneous rocks and has been regarded as the 9th most abundant element on the earth's surface (Emsley, 2011). Titanium found application in desalination plants as it helps in converting sea water to fresh water. It has been proven over the years as non-toxic substance and has no biological role. Hence, there is no specific guideline regarding the level of titanium that is expected to be in the soil and this may be attributed to its non-toxic nature either to us as human or to the environment in general.

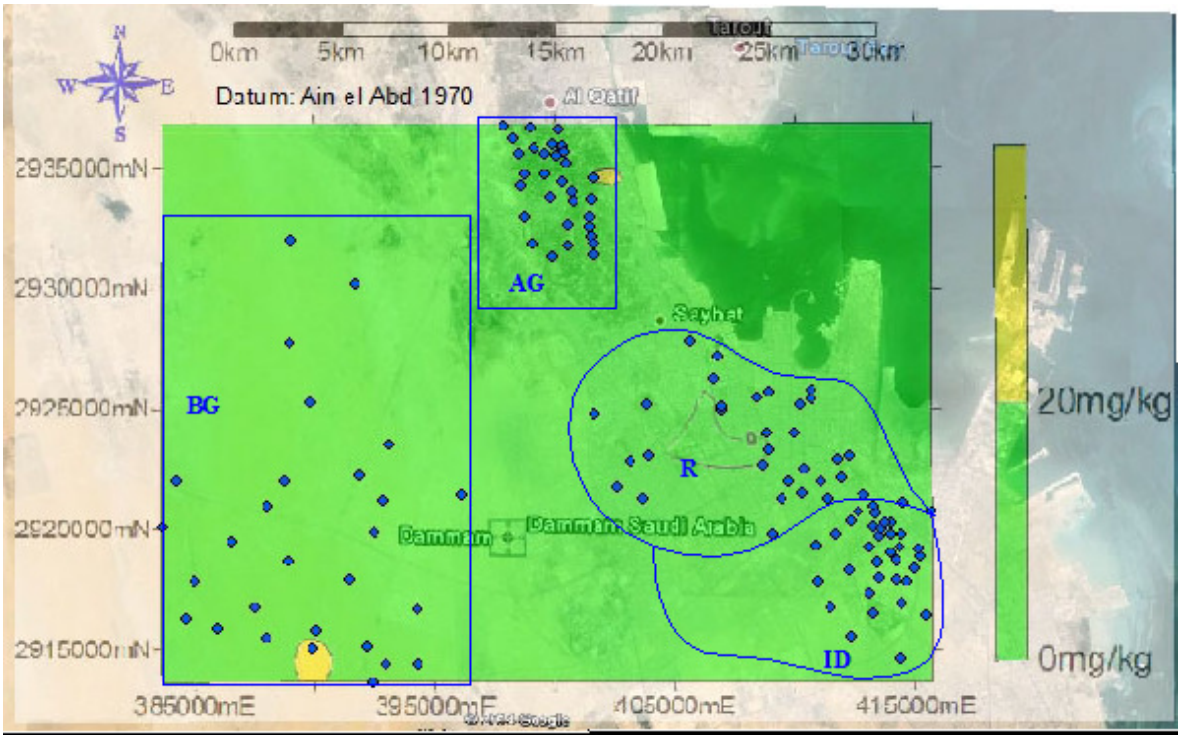

Figure 4.11 Spatial Distribution of Vanadium Concentrations.

Vanadium does not really exist naturally in the earth's crust, but it is in compounds of sixty five different minerals (Magyar, 2011). Vanadium can be found in bauxite and fossil fuel deposit at a concentration of about 1200 ppm (Pearson and Green, 1993). Anke (2004) reported that about 110,000 tons of V is released into the environment per year by burning fossil fuel and this may have health effect if not properly managed. The ACGIH estimated 0.2 mg / m^3 as the allowable limit of exposure for 8 hours of work per day. The Canadian Environmental Soil Quality Guidelines sets 130 mg/kg as the values expected to be present in soil. The results obtained thereby falls within the allowable limit in soil. Thus, no hotspot was detected for V in topsoil of the sampling area.

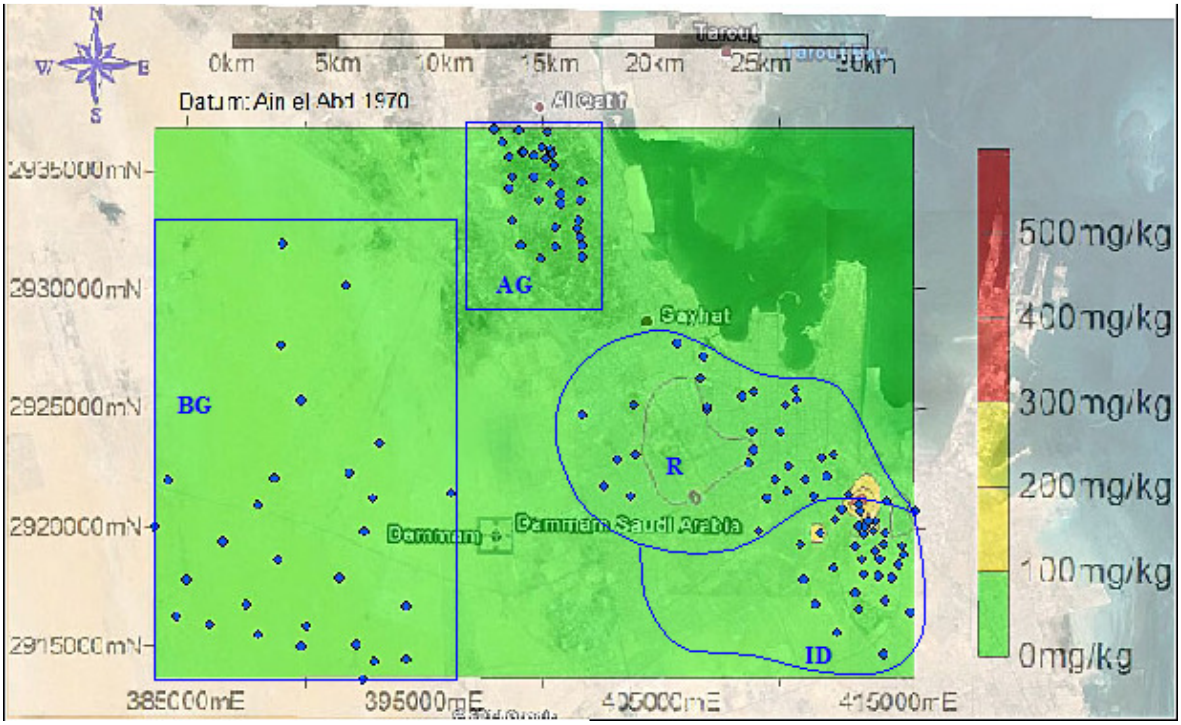

Figure 4.12 Spatial Distribution of Zinc Concentrations.

Zinc is an essential trace element that is required in trace amount for human health. It plays an important role in maintenance of vision and boost human immune system. Although, Zn is an essential element for body metabolism, its abuse or excessive intake may be harmful (Fosmire, 1990). The adopted specification for the level of Zn in the soil specifies 200 mg/kg for agricultural and residential area while 360 mg/kg is specified for industrial area. The allowable limit was exceeded in some of the industrial samples which may be attributed to industrial release of Zn containing materials. It should be noted that despite the compliance of most of this trace metals with the adopted guidelines, continuous monitoring of the soil and the environment in general will be of great importance to the region.

4.5 Correlation of Results with the Soil Types and Site Activities

There is no clear factor responsible for bioavailability of arsenic in soil (Fitz and Wenzel, 2006). In soil, its bioavailability has been traced to the uptake of As containing compounds by plant from the soil. McLaren et al., (2006), associate As in soil to their oxides and hydroxides. Clay, oxides of Fe and Al, and organic matter content of the soil among other factors has also been linked to the retention of As in soil (Mench et al., 2009). Considering the soil type in our sampling area which is majorly sand with silt; there is a possibility of As containing compound to penetrate the sand while the silt with high surface area will be able to retain As containing compound. However, the period of retention by silt may also be considered in further studies. It should be noted that the levels of As in all samples analyzed fall within the allowable limit. Soil characteristic is responsible for transport of barium compounds in soil (ATSDR, 2007). It may precipitate as sulfates and also as carbonates. Barium is usually attached to clay minerals and fine soil particles, but its mobility is limited by the availability of water insoluble salt and its inability to form soluble humic complexes (WHO, 1990). The result indicate that Ba

concentration in soil is within the allowable limit except for industrial sample 12 which is a poorly graded sand with silt and gravel. The possibility of Ba to attach with silt content of the soil is limited because of their small percentage in soil compared to the percentage of sand and gravel. However, continuous assessment of Ba levels in soil is necessary for effective management of the environment and decision making.

Clay minerals have the potentials to adsorbed cadmium or Cd containing compound as oxides, carbonate, and hydroxide. It has also been proved as an effective means of removing Cd in soil (Dudley et al., 1991). The concentration and adsorption of Cd in soil has also been attributed to soil pH and clay content in the soil. The soil type in our sampling location is of sandy soil with silt and gravel in some, therefore, the possibility of absorption of Cd containing compound is limited since the clay content of the soil is very low. However, ample care must be taken for effective protection of the environment and clean up approach should be adopted for polluted area.

The interaction of Cr with soil surfaces is restricted to positively charged exchange site and the interaction usually decreases with increase soil pH (Ainsworth et al., 1989). Oxides of Fe and total manganese are also responsible for the mobility of Cr containing compound and clay soil has the capability to prevent penetration of Cr containing compound to ground water. The samples analyzed contain elevated levels of Cr in some of the samples and the soil types are generally poorly graded soil with silt and little percentage of clay. The present study does not assess the soil pH in the sampling location and is thereby recommended in future studies relating to soil for effective judgment of Cr retention and penetration in soil.

Copper adsorb to soil, especially clay soil than any other metals with the exception of Pb (Cavallaro and McBride, 1978). It has also been established to have high empathy for soluble organic matter and the formation of such organic matter may increase the mobility of Cu in soil (Cavallaro and McBride, 1978). They also stated precipitation as a useful tool in the

behavior and retention of Cu containing compound in the soil. Rainfall which is stated as the contributing factor to the behavior of Cu rarely fall in the sampling location and most of the sample analyzed except for industrial sample 17 and 18 also fall within the allowable limit expected to be found in soil. The soil type in the two samples that shows the elevated concentration of Cu are silty sand, thereby, the possibility of retention of Cu containing compound is low.

The behavior of Hg in soil depends on soil pH and redox potential (Joan and Bert, 1992). However, clay soil adsorbed Hg and the adsorption rate increases with increase pH. The soils in the sampling locations are sandy soil with silt and the levels of Hg in the analyzed samples are within the allowable range expected to be present in soil.

The retention of Ni in soil is possible by adsorption means only and is usually attached to clay, oxides of Fe, and Mn (Joan and Bert, 1992). The clay content in the soil of the sampling location are very small, therefore, the possibility of retention of Ni in the soil is limited. However, the levels of Ni in all the samples analyzed fall within the allowable limit expected to be found in soil.

The use of Pb in gasoline and its emission in the production of paint, plumbing materials, batteries, and fossil fuel combustion has been attributed to its release into the environment which usually comes back to soil in form of dry or wet atmospheric deposition. The reactions and behaviors of Pb in soil depend on pH value of the soil and such reaction such as adsorption usually takes place in clay soil (Joan and Bert, 1992). The clay content in the soils analyzed is very small and the levels of Pb in all the samples analyzed are within the allowable range expected to be found in soil.

Zinc, which is an essential mineral for body metabolism in human, is usually adsorbed to clay material. His concentrations, behaviors, and mobility in soil have also been attributed to the presence of oxides of Fe and Mn.

In general, the 132 soil samples analyzed contain >50 % sand, with little gravel, silt, and rarely clay. This indicates the limitation of the soil in retaining the metals content in the soil. However, most of the samples analyzed are within the allowable range expected to be found in soil. Future research on soil metal content in the area should consider the pH values and redox potentials of the soil at sampling locations for accurate and effective correlation between the soil and the metal content of the soil.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Contamination level assessment of trace metals in the selected zones (agricultural, industrial, residential, and background areas) was carried out. Presently, Saudi Arabia has no specific guidelines regarding the level of trace metals that should be present in soil. However, Canadian Environmental Quality Guidelines regarding the level of trace metals in soil were adopted for this study.

In general, the result obtained indicate that As seems to be more available in agricultural area than all other sampling locations, Ba is at high level in some part of the industrial area, Cd has high level of concentration in some part of residential and industrial area with a shocking result of Cd been found at higher concentration in one of the background samples. Cr is higher in industrial area with a warning sign around residential area, Cu seems to fall within the allowable range except for some points along the industrial area that give a warning sign. In the case of Fe, there is no specific regulation regarding the amount of Fe that should be present in the soil which may be attributed to the fact that Fe is not regarded as one of the toxic metals in the environment. The results also indicate that Pb and Hg do not exceed the allowable range that should be available in soil. Nickel fall within the allowable range in background and residential samples but give a warning sign in agricultural and industrial samples. Vanadium and Zn also fall within the permissible range that should be present in soil based on the adopted guideline.

The aim of this thesis, to assess the spatial distribution of the levels of trace metals in the selected zones in Dammam area, was successfully achieved. The results obtained indicate that only some of the samples collected and analyzed exceeded the permissible range that could be available in soil.

5.2 Recommendations

In view of the result obtained, the following recommendation is made:

- Concerned academic departments in KFUPM and other universities in conjunction with the relevant agency in the Kingdom could collaborate for continuous assessment of the soil within Dammam area and Eastern province in general in order to establish reliable guidelines for the Kingdom of Saudi Arabia.
- The assessment of trace metals in the environment should also be extended to the levels of trace metals in plant and that of air.
- Further research also be carried out on the levels of trace metals in soil, plant, air based on different seasons (winter and summer).
- The research should also be extended to the level of trace metals in soil with depth and their interaction with the soil of the region.
- Future research should also consider the sources of the trace metals.

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Appendix A: Some of the Equipment Used For Sample Collection, Preparation and Analyzes.

Figure A1: Auger used during sample collection.

Figure A2: Soil samples collected.

Figure A3: Stack of sieves including pan and cover.

Figure A4: Grinding/ crushing machine.

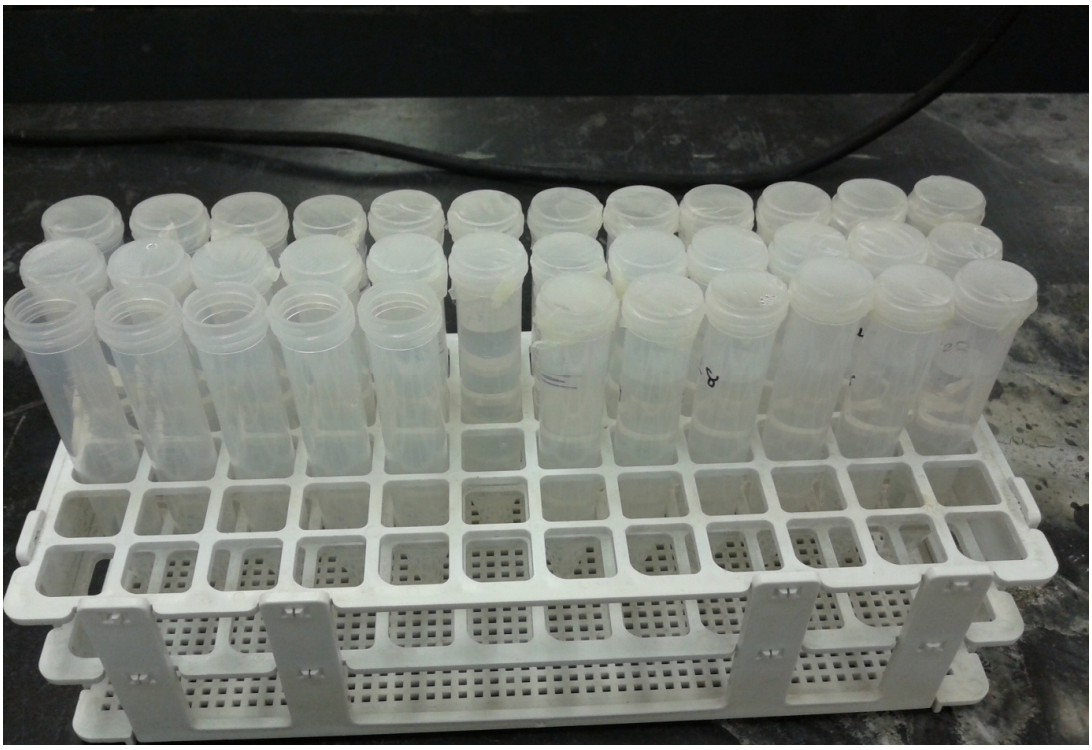

Figure A5: Measured samples ready for digestion.

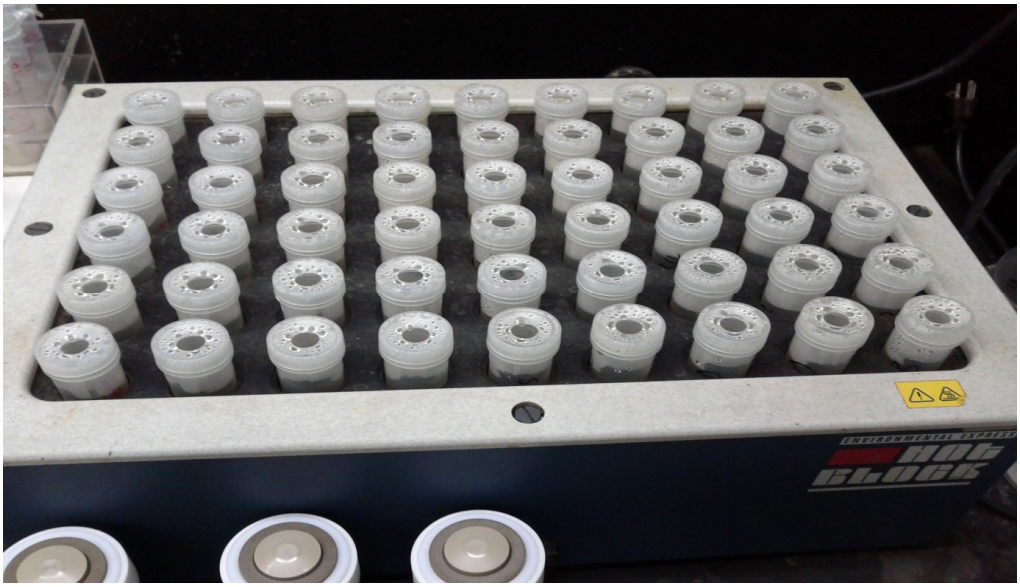

Figure A6: Digestion operation taken place.

Figure A7: The ICP – OES System.

Figure A8: Filtration after sample digestion.

APPENDIX B: Calibration Curves for ICP-OES

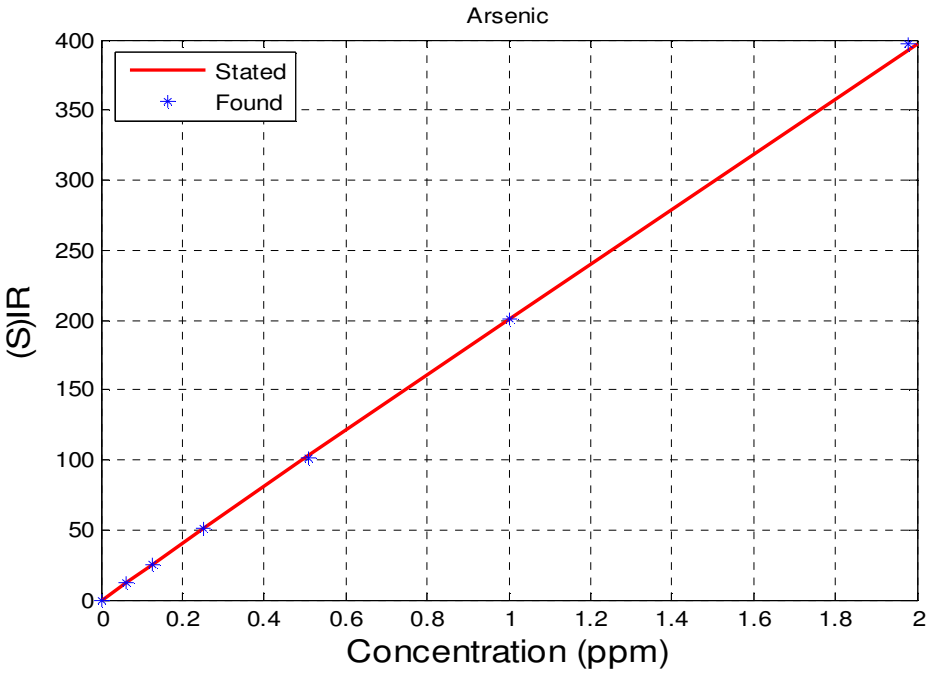

Figure B1: Arsenic calibration curve

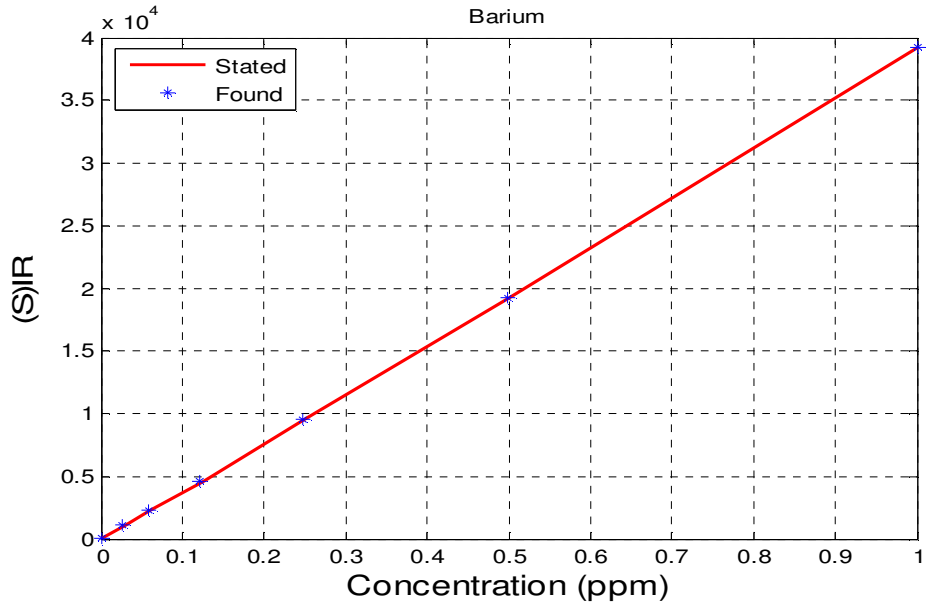

Figure B2: Barium calibration curve.

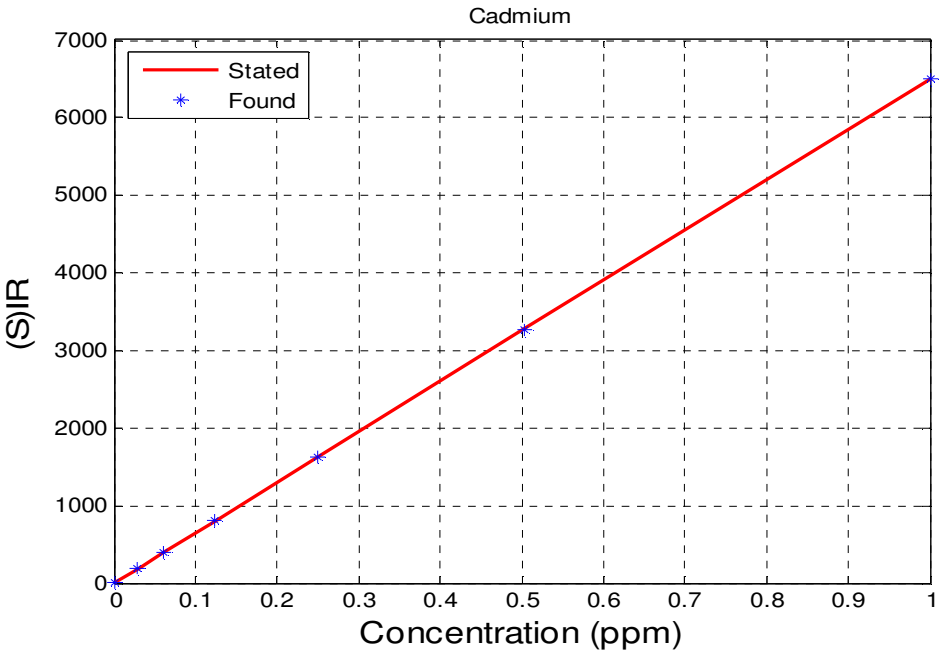

Figure B3: Cadmium calibration curve.

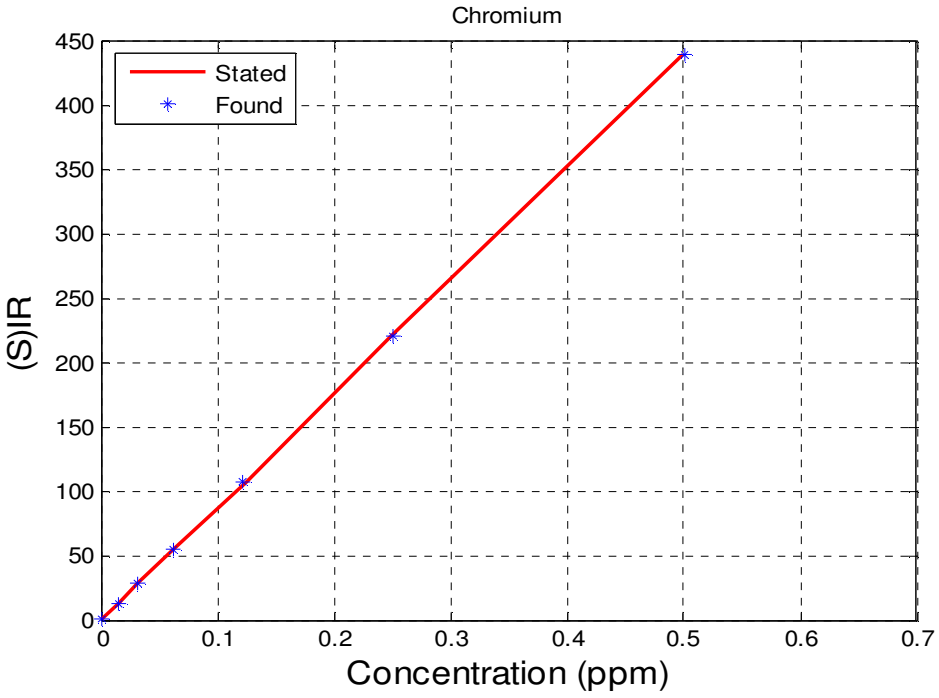

Figure B4: Chromium calibration curve.

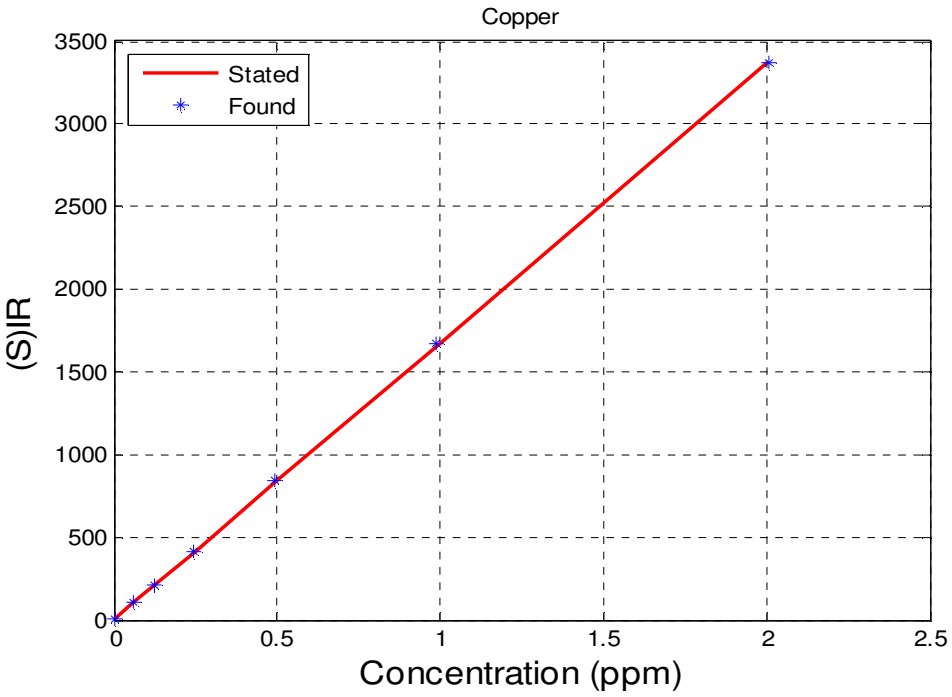

Figure B5: Copper calibration curve.

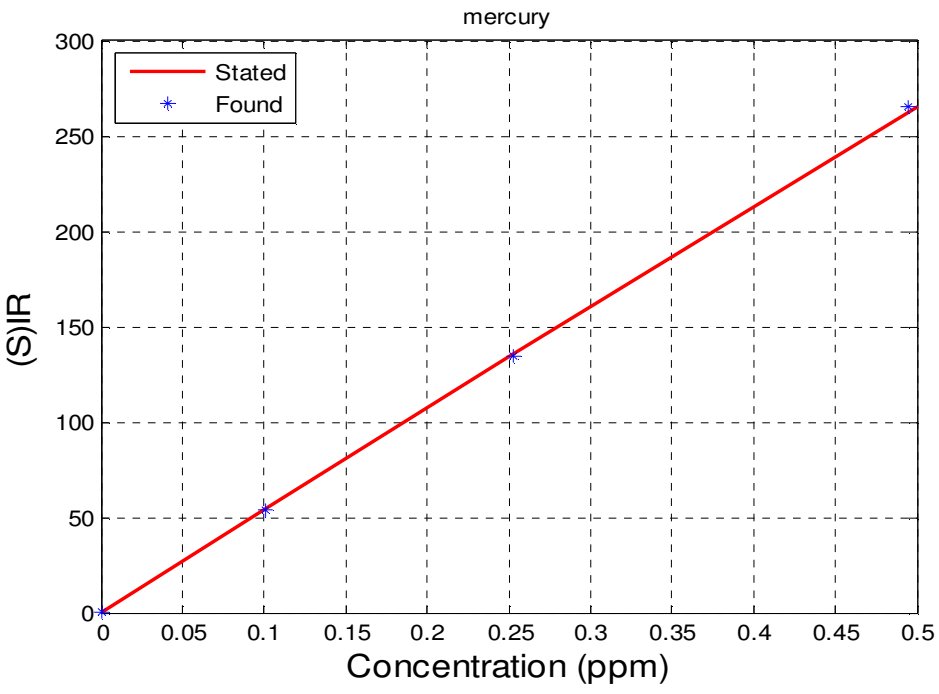

Figure B6: Mercury calibration curve.

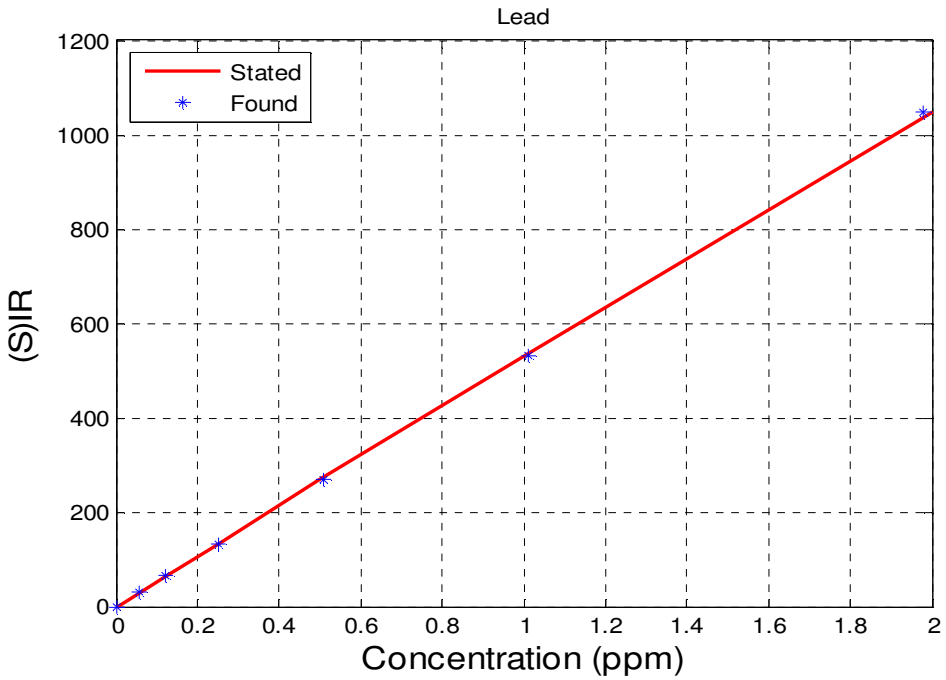

Figure B7: Lead calibration curve.

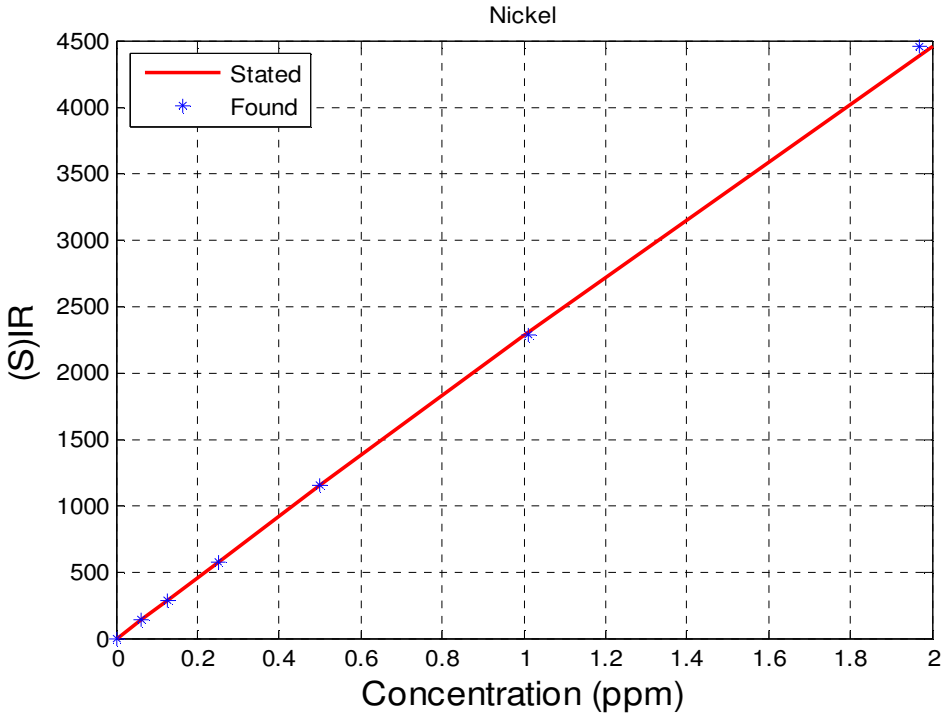

Figure B8: Nickel calibration curve.

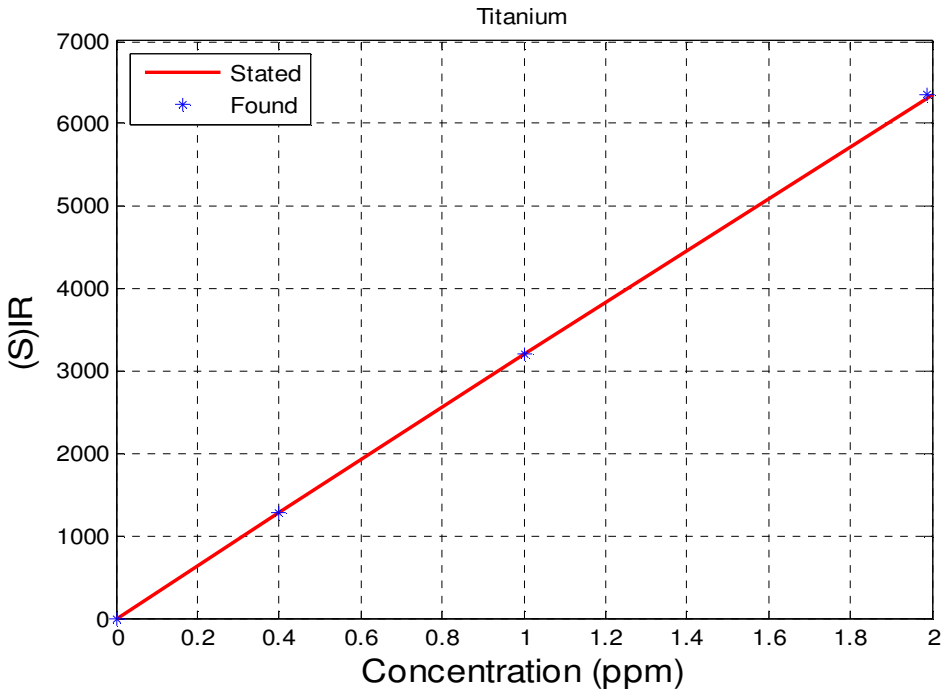

Figure B9: Titanium calibration curve.

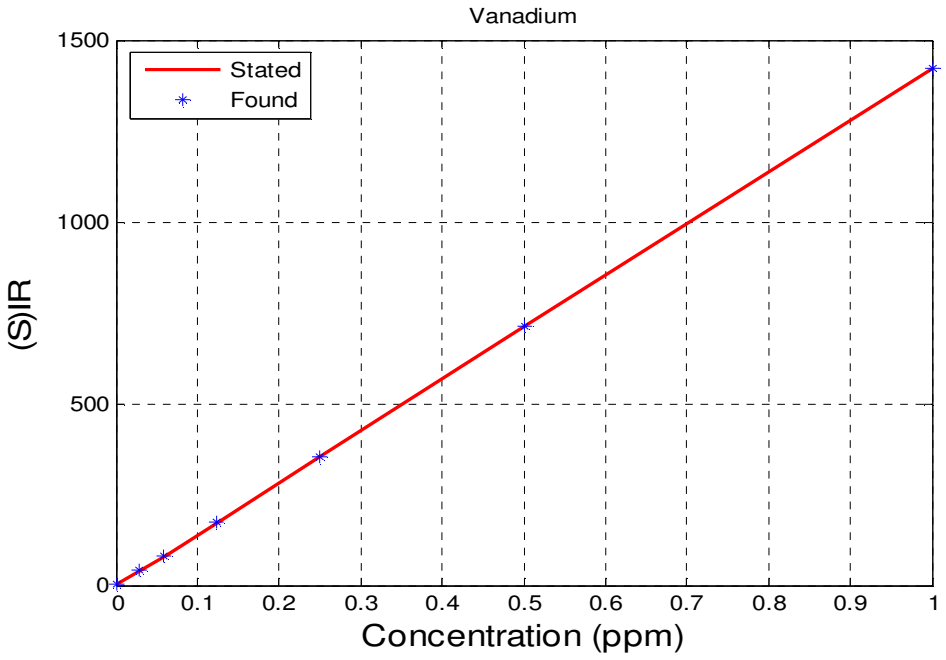

Figure B10: Vanadium calibration curve.

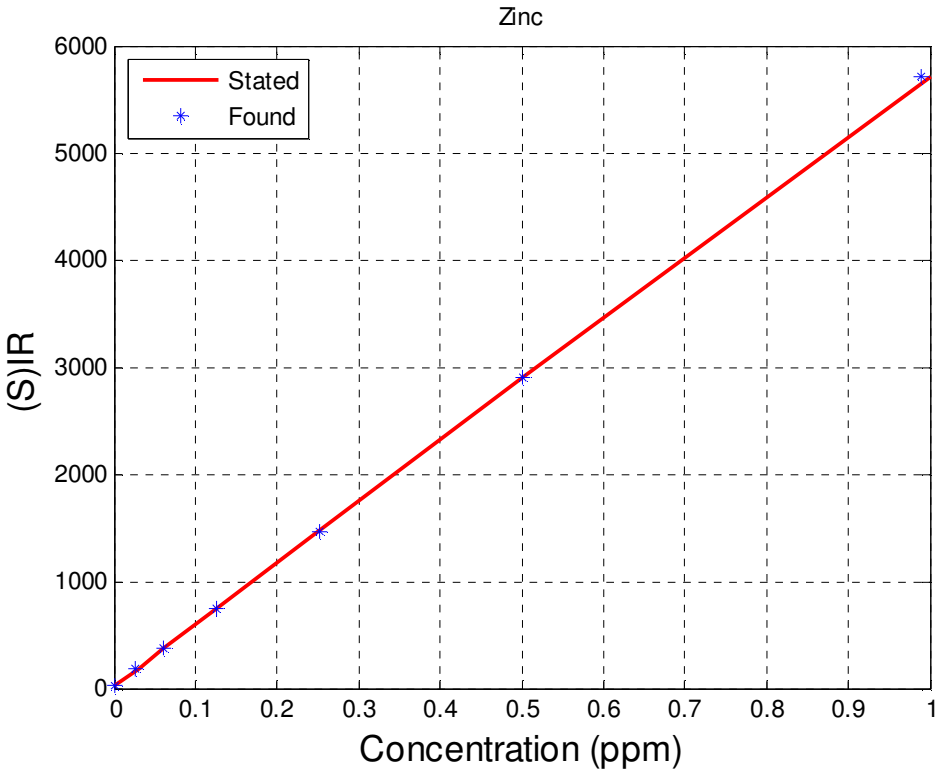

Figure B11: Zinc calibration curve.

Appendix C: ICP-OES QA/QC Results

Table B: ICP – OES QA/QC Results

Sample No.	**As (mg/kg)**	**Ba (mg/kg)**	**Cd (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Hg (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Ti (mg/kg)**	**V (mg/kg)**	**Zn (mg/kg)**
IDL**	**0.002**	**0.0002**	**0.0001**	**0.002**	**0.001**	**0.00007**	**0.0003**	**0.001**	**0.0006**	**0.002**	**0.00001**
PQL***	**0.010**	**0.001**	**0.001**	**0.010**	**0.005**	**0.0004**	**0.002**	**0.005**	**0.003**	**0.010**	**0.000**

QC	**As1890**	**Ba4554**	**Cd2288**	**Cr2677**	**Cu3247**	**Hg1849**	**Ni2316**	**Pb2203**	**Ti3349**	**V_2924**	**Zn2138**
ICV	0.5	0.25	0.25	0.25	0.5	0.25	0.5	0.5	0.5	0.25	0.25
CCVSTD 1	0.063	0.031	0.031	0.016	0.063	0.016	0.031	0.031	0.031	0.031	0.031
CCVHCSSTD 3											10
CCVHCSSTD 4											
LCS/LCSD	0.1	0.05	0.05	0.05	0.1		0.1	0.1		0.05	0.05
MS/MSD	0.1	0.05	0.05	0.05	0.1		0.1	0.1		0.05	0.05
ppm*	**As1890**	**Ba4554**	**Cd2288**	**Cr2677**	**Cu3247**	**Hg1849**	**Ni2316**	**Pb2203**	**Ti3349**	**V_2924**	**Zn2138**
LCS1	0 .1008	0.0534	0 .0513	0.0543	.1045	.0007	0.1005	.0999	.0008	0.0504	0.0543
LCS1D	0.1004	0 .0516	0 .0599	0.0511	.1004	.0008	0.1005	.0980	.0007	0.0508	0.0559

LCS 2	0.1001	0.0587	.0532	0.0529	.1024	.0001	0.1004	.1072	.0008	0.0509	0.05
LCS 2D	0.1003	0.0578	0.0528	0.0521	.1004	.0006	0.1006	0.106	.0007	.0579	0.0539
LCS 3	.1983	.1116	.0979	.1086	0.2193	.0002	0.2154	.1960	.0001	.1079	.0077
LCS 3D	0.1964	.1161	0.0932	0.1074	.2164	.0000	.2160	0.1948	0.0005	0.1039	0.0049
LRB 1	0.0057	.0035	.0002	.0020	.0003	.0006	.0000	0.001	.0008	0.002	0.0865
LRBD	0.0041	.0054	.0003	.0001	.0029	.0010	0	0.0006	.0010	0.0006	0.0878
LRB2	0.0061	.0033	.0001	.0018	0.0016	.0006	.0014	0.0011	.0005	0.001	0.0903
LRB2D	0.0046	.0034	.0002	.0003	0.0009	.0011	.0005	0.0008	.0007	0.0007	0.0905
ppm*	**As1890**	**Ba4554**	**Cd2288**	**Cr2677**	**Cu3247**	**Hg1849**	**Ni2316**	**Pb2203**	**Ti3349**	**V_2924**	**Zn2138**
IDL**	**0.002**	**0.0002**	**0.0001**	**0.002**	**0.001**	**0.00007**	**0.0003**	**0.001**	**0.0006**	**0.002**	**0.00001**
PQL***	**0.010**	**0.001**	**0.001**	**0.010**	**0.005**	**0.0004**	**0.002**	**0.005**	**0.003**	**0.010**	**0.000**
QC	**As1890**	**Ba4554**	**Cd2288**	**Cr2677**	**Cu3247**	**Hg1849**	**Ni2316**	**Pb2203**	**Ti3349**	**V_2924**	**Zn2138**
ppm*	**As1890**	**Ba4554**	**Cd2288**	**Cr2677**	**Cu3247**	**Hg1849**	**Ni2316**	**Pb2203**	**Ti3349**	**V_2924**	**Zn2138**
ICV	0.5	0.25	0.25	0.25	0.5	0.25	0.5	0.5	0.5	0.25	0.25
CCVSTD 1	0.063	0.031	0.031	0.016	0.063	0.016	0.031	0.031	0.031	0.031	0.031
CCVHCSSTD 3											10

CCVHCSSTD 4											
LCS/LCSD	0.1	0.05	0.05	0.05	0.1		0.1	0.1		0.05	0.05
MS/MSD	0.1	0.05	0.05	0.05	0.1		0.1	0.1		0.05	0.05
LCS1	0 .1008	0.0534	0 .0513	0.0543	.1045	.0007	0.1005	.0999	.0008	0.0504	0.0543
LCS1D	0.1004	0 .0516	0 .0599	0.0511	.1004	.0008	0.1005	.0980	.0007	0.0508	0.0559
LCS 2	0.1001	0.0587	.0532	0.0529	.1024	.0001	0.1004	.1072	.0008	0.0509	0.05
LCS 2D	0.1003	0.0578	0.0528	0.0521	.1004	.0006	0.1006	0.106	.0007	.0579	0.0539
LCS 3	.1983	.1116	.0979	.1086	0.2193	.0002	0.2154	.1960	.0001	.1079	.0077
LCS 3D	0.1964	.1161	0.0932	0.1074	.2164	.0000	.2160	0.1948	0.0005	0.1039	0.0049
LRB 1	0.0057	.0035	.0002	.0020	.0003	.0006	.0000	0.001	.0008	0.002	0.0865
LRBD	0.0041	.0054	.0003	.0001	.0029	.0010	0	0.0006	.0010	0.0006	0.0878
LRB2	0.0061	.0033	.0001	.0018	0.0016	.0006	.0014	0.0011	.0005	0.001	0.0903
LRB2D	0.0046	.0034	.0002	.0003	0.0009	.0011	.0005	0.0008	.0007	0.0007	0.0905
LRB	0.0001	.0067	0	.0005	0.0028	0.0001	.0005	0.0021	0.0001	.0003	0.0911
ppm*	**As1890**	**Ba4554**	**Cd2288**	**Cr2677**	**Cu3247**	**Hg1849**	**Ni2316**	**Pb2203**	**Ti3349**	**V_2924**	**Zn2138**
LRBdup	0.0017	.0046	0.0001	0.0003	0.0027	0.0002	0.0005	0.001	0	0.0003	0.0913
LRB 4	0.0011	.0017	.0002	.0004	0.0016	0.0002	0.0006	.0022	.0019	.0001	0.0765
LRB 4D	0.0031	.0012	.0001	0.0008	0.0021	.0008	0.0004	0.002	.0010	.0005	0.0759
AG3	.0231	1.196	.0011	.7738	.6328	.0023	.2054	0.1951	2.359	.2613	0.4977
AG3D	.0234	1.224	.0012	.7741	0.6314	.0009	0.2064	.1942	2.348	.2668	.4942

AG3MS	.1182	1.244	.0389	0.7937	0.6926	.0019	.2517	.2306	2.45	.2877	.4639
AG3MSD	0.115	1.253	0.0375	.7962	0.699	.0005	0.2565	0.2322	2.445	0.2843	0.4612
R5MS	.1769	.9544	.0796	1.322	.3057	.0002	0.2475	.3926	1.988	.2557	.3374
R5MSD	0.1721	0.9554	.0724	1.319	0.3042	.0001	.2460	0.3935	1.936	0.2564	0.3358
R5	.0154	.8025	.0003	1.161	.1193	.0002	.1336	.2585	1.831	.1582	.2139
R5D	.0154	.8025	.0003	1.161	.1193	.0002	.1336	.2585	1.831	.1582	.2139
MSD12	.1344	39.24	.0408	1.331	.2353	.0058	.3041	.1836	4.149	.3675	1.004
MS12	.1316	39.39	.0416	1.336	.2505	.0055	.3076	.1865	4.190	.3779	1.038
ID12	.0351	39.33	.0006	1.155	.1510	.0049	.2411	.1222	4.761	.2986	1.002
ID12D	.0328	39.37	.0005	1.158	.1530	.0057	.2391	.1304	4.203	0.2953	.9679

Appendix D: Tabulated Trace Metals Levels in Soil

Table D1: Tabulated Trace Metals Levels in Soil for Agricultural Area Samples

Sample No.	**As (mg/kg)**	**Ba (mg/kg)**	**Cd (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Hg (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Ti (mg/kg)**	**V (mg/kg)**	**Zn (mg/kg)**
IDL**	**0.002**	**0.0002**	**0.0001**	**0.002**	**0.001**	**0.00007**	**0.0003**	**0.001**	**0.0006**	**0.002**	**0.00001**
PQL***	**0.010**	**0.001**	**0.001**	**0.010**	**0.005**	**0.0004**	**0.002**	**0.005**	**0.003**	**0.010**	**0.000**
Allowable Limit	12	750	1.4	64	63	6.6	50	70		130	200
AG1	1.02	100.65	0.035	33.91	10.62	0	8.695	4.28	117.15	15.205	7.53
AG2	0.845	42.725	0.055	66.85	27.95	0.14	10.225	7.95	111.25	12.61	25.805
AG3	1.155	59.8	0.055	38.69	31.64	0.115	10.27	9.455	117.95	13.065	24.385
AG4	1.165	23.84	0.135	11.73	10.515	0.065	4.6	5.03	24.225	3.59	8.425
AG5	0.685	70.95	0.02	33.4	15.08	0.04	8.545	7.775	129.3	11.67	10.465
AG6	1.185	32.965	0.03	36.815	14.525	0.06	9.8	10.25	147.35	14.565	46.725
AG7	1.37	32.925	0.025	37.405	11.4	1.205	9.42	52.35	164.2	18.02	9.21

AG8	0.845	48.385	0.005	74.7	9.84	0.03	9.615	6.595	160.5	12.245	10.28
AG9	1.415	8.505	0.075	10.32	1.1	0.035	5.685	2.205	13.615	1.82	8.21
AG10	1.1	44.35	0.015	11.625	2.18	0.035	6.16	3.55	21.455	2.745	3.455
AG11	1.365	37.58	0.025	45.31	8.455	0.085	9.88	5.52	113.45	11.275	15.54
AG12	1.39	8.18	0.055	5.635	1.535	0.035	6.095	1.535	9.75	2.245	9.075
AG13	1.165	10.845	0.07	5.015	2.01	0.025	5.895	2.255	26.945	2.35	3.895
AG14	1.045	10.69	0.04	3.925	1.245	0.05	5.795	3.365	8.49	2.335	5.85
AG15	1.2	12.55	1.135	7.205	0.97	0.095	6.305	1.405	6.23	1.635	6.67
AG16	1.52	31.72	0.02	21.665	8.855	0.07	8.195	6.48	118.15	11.23	7.385
AG17	0.91	7.8	0	4.07	1.705	0.065	6.845	2.94	7.895	2.235	2.83
AG18	1.925	46.815	0.01	23.48	12.35	0.02	10.385	13.87	147.7	16.05	20.95
AG19	1.05	18.95	0.145	3.03	1.36	0.025	7.415	2.93	0.075	1.775	3.82
AG20	3.135	62.5	0.035	23.245	10.375	0.115	10.395	13.62	126.7	17.765	22.215
AG21	2.495	23.145	0	26.03	9.31	0.01	12.485	5.135	157.6	18.06	12.63

AG22	2.815	32.625	0.025	33.15	10.435	0.07	16.25	7.235	169.3	21.885	17.58
AG23	2.38	33.895	0.03	15.97	6.265	0.055	8.67	2.58	102	14.56	10.08
AG24	1.93	27.275	0.01	14.255	5.86	0.16	8.025	2.685	112.1	12.615	8.055
AG25	2.42	29.755	0.025	14.505	7.085	0.015	8.525	4.19	99.25	14.73	12.23
AG26	2.295	32.84	0.03	28.64	8.18	0.07	13.03	2.81	154.75	19.03	10.995
AG27	2.025	29.295	0.02	18.595	5.67	0.06	11.065	1.465	159.1	17.095	5.995
AG28	1.48	35.695	0.025	18.505	6.815	0.03	9.555	2.865	127.2	13.39	13.665
AG29	1.47	39.6	0.05	34.51	10.555	0	13.425	6.96	146.65	17.67	12.9
AG30	1.93	47.04	0.03	26.615	16.175	0.04	12.495	4.61	151.85	17.995	17.725
AG31	0.45	21.655	0.01	22.99	2.3	0.03	8.385	0.9	123.55	7.95	1.015
AG32	1.425	31.705	0.03	25.335	7.53	0.005	10.565	4.605	128.8	15.395	26.355
AG33	1.415	39.865	0.035	29.555	8.515	0.02	11.685	4.86	146.15	15.59	8.28

Table D2: Tabulated Trace Metals Levels in Soil for Industrial Area Samples

Sample No.	**As (mg/kg)**	**Ba (mg/kg)**	**Cd (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Hg (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Ti (mg/kg)**	**V (mg/kg)**	**Zn (mg/kg)**
IDL**	**0.002**	**0.0002**	**0.0001**	**0.002**	**0.001**	**0.00007**	**0.0003**	**0.001**	**0.0006**	**0.002**	**0.00001**
PQL***	**0.010**	**0.001**	**0.001**	**0.010**	**0.005**	**0.0004**	**0.002**	**0.005**	**0.003**	**0.010**	**0.000**
Allowable Limit	12	2000	22	87	91	50	50	600		130	360
ID1	0.95	22.1	0.025	6.13	0.55	0.05	5.7	0.53	4.96	1.21	4.32
ID2	1.105	11.65	3.93	2.79	0.285	0.07	5.51	0.475	5.865	1.175	2.05
ID3	2.475	0	0.005	26.985	4.4	0.045	10.375	7.175	306.35	14.775	29.605
ID4	0.88	84.3	28.685	4.44	0.18	0.09	7.52	0.035	1.645	1.115	4.255
ID5	1.305	122.85	13.23	5.235	0.88	0.07	5.835	1.92	9.07	0.94	5.985
ID6	1.335	1.14	14.12	0.12	0.195	0.08	4.755	0.71	4.155	0.085	0.095
ID7	0.82	409.2	0	37.19	3.73	0.01	10.09	1.555	216.4	11.895	7.05
ID8	0.83	89	0.005	23.125	3.59	0.03	9.94	2.255	238.95	12.235	9.735

ID9	1.13	513.5	0.045	44.305	7.075	0.045	14.46	3.105	221.35	14.055	69.75
ID10	1.195	290.2	0.015	29.225	3.695	0.025	18.305	1.93	350.2	18.315	12.81
ID11	1.235	293.85	0.025	28.415	3.725	0.03	18.665	1.835	340.1	18.33	13.55
ID12	1.755	1966.5	0.03	57.75	7.55	0.245	12.055	6.11	188.05	14.93	50.1
ID13	1.845	1379.5	0.085	149.1	15.415	0.03	14.075	7.12	157.3	19.625	147
ID14	1.685	513.5	0.02	122.65	9.395	0.055	13.325	5.72	223.6	15.865	38.86
ID15	1.05	462.5	0.755	162.9	17.965	1.44	17.22	69.05	327.2	18.165	73.4
ID16	1.345	599.5	0.065	56.95	22.9	0.695	15.74	23.36	214.2	14.7	149.3
ID17	2.135	722	0.095	247.6	95.75	0.165	45.195	100.25	281.7	17.1	676.5
ID18	2.055	701.5	0.085	235.6	95.55	0.145	42.205	97.75	276.75	16.615	655.5
ID19	1.47	120.9	0.075	27.75	3.995	0.025	13.29	1.56	215.75	16.495	8.05
ID20	3.8	0	0.08	23.71	7.385	0.075	11.595	16.22	184.4	14.88	63.7
ID21	4.56	0	0.065	17.025	4.71	0.045	6.93	10.3	123.6	10.66	29.89
ID22	1.775	1131.5	0.03	18.54	3.895	0.03	8.1	2.165	76.7	15.545	8.055

ID23	1.31	566.5	0.05	26.55	4.585	0.02	9.87	2.585	149.15	14.59	15.66
ID24	1.82	452.9	0.065	18.615	3.935	0.03	7.83	2.755	87.45	17.17	8.985
ID25	0.515	42.73	0.01	21.95	1.955	0.045	8.06	0.605	130	8.385	0.535
ID26	0.965	70.5	0.01	57.5	3.99	0.035	15.71	1.38	311.35	16.785	6.395
ID27	1.1	130.4	0.09	46.99	3.285	0.02	7.035	0.805	119.8	10.86	4.265
ID28	0.755	32.59	0.015	29.175	2.485	0.005	8.775	0.74	182.55	9.83	4
ID29	1.07	58.75	0.015	23.12	3.405	0.025	15.225	1.15	311.85	16.985	7.12
ID30	1.655	97.45	0.05	91.75	5.88	0.06	15.175	1.48	361.1	19.965	11.48
ID31	1.075	90.7	0.04	23.91	3.25	0.025	13.13	1.255	217.75	14.415	10.88
ID32	2.765	36.57	0.1	25.095	15.05	0.025	13.185	1.86	260.45	14.725	20.785
ID33	2.245	52.45	0.06	16.37	2.345	0.005	8.84	1.205	121.2	20.415	10.12

Table D3: Tabulated Trace Metals Levels in Soil for Residential Area Samples

Sample No.	**As (mg/kg)**	**Ba (mg/kg)**	**Cd (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Hg (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Ti (mg/kg)**	**V (mg/kg)**	**Zn (mg/kg)**
IDL**	**0.002**	**0.0002**	**0.0001**	**0.002**	**0.001**	**0.00007**	**0.0003**	**0.001**	**0.0006**	**0.002**	**0.00001**
PQL***	**0.010**	**0.001**	**0.001**	**0.010**	**0.005**	**0.0004**	**0.002**	**0.005**	**0.003**	**0.010**	**0.000**
Allowable limit	12	500	10	64	63	6.6	50	140		130	200
R1	1.12	0.765	0	0.23	0.5	0.08	4.97	3.77	12.675	0.655	0.055
R2	1.365	0.51	2.245	0.12	0.135	0.09	4.535	1.55	1.085	0.085	0.085
R-3	0.76	44.465	0.015	43.55	6.845	0.09	5.675	4.045	90.95	7.54	14.245
R4	0.125	60.5	0.03	24.57	6.6	0.585	13.23	18.635	232.8	17.725	30.535
R-5	0.845	45.265	0.02	65.45	6.735	0.035	7.375	14.275	101.7	9.085	12.205
R6	1.135	0.85	23.005	0.24	0.235	0.13	4.99	2.555	1.58	0.09	0.395
R7	1.15	0.36	5.03	0.125	0.04	0.075	3.82	1.29	1.055	0.07	0.01
R8	1.22	0.33	3.55	0.195	0.19	0.1	2.245	0.805	3.095	0.05	0.205

R-9	1.07	47.635	0.01	85.9	5.01	0.03	8.06	1.945	148.1	9.565	7.48
R10	0.975	0.91	9.835	0.07	0.265	0.05	3.395	0.41	8.115	0.015	0.22
R11	1.045	0.485	3.465	0.335	0.065	0.095	2.835	0.965	2.995	0.075	0.075
R12	0.695	24.27	0.03	29.275	3.135	0.02	5.985	1.225	83.55	6.69	4.82
R13	0.655	23.655	0.035	27.73	2.925	0.005	5.735	1.24	78.4	6.295	4.205
R-14	0.91	49.32	0.025	37.925	3.32	0.075	6.28	1.005	113.35	10.875	1.835
R15	0.925	35.375	0.03	45.495	6.675	0.005	8.465	4.185	152.65	10.165	9.52
R16	1.04	0.735	2.945	0.29	0.175	0.085	3.135	0.68	4.15	0.11	0.32
R-17	0.71	31.16	0.005	26.73	4.055	0.01	4.91	1.75	79.25	6.795	4.865
R-18	1.765	54.6	0.035	89.65	5.58	0.05	9.09	2.265	117.75	13.755	10.615
R-19	0.965	25.91	0.02	12.37	2.45	0.04	4.48	1.08	80.05	6.83	1.65
R20	0.935	1.49	11.25	0.215	0.245	0.09	4.665	0.08	6.885	0.125	0.25
R-21	0.805	30.36	0.015	18.45	2.625	0.01	5.52	1.345	94.1	6.73	2.13
R-22	1.28	62.35	0.03	33.795	4.765	0	7.86	14.345	130.4	10.285	10.415

R-23	2.22	79.3	0.055	31.825	4.305	0.015	7.22	3.105	102.55	14.53	11.32
R-24	1.155	70	0.03	120.2	6.48	0.02	9.82	5.59	137.85	12.285	21.91
R-25	0.72	81.05	0.005	44.92	3.745	0	6.145	3.14	109.55	8.62	7.515
R-26	0.455	34.445	0.005	23.805	2.84	0.01	7.155	0.985	137.75	7.855	2.635
R-27	1.205	98.55	0.08	39.68	7.01	0.01	6.36	25.6	101.75	12.3	21.95
R-28	1.025	52.6	0.045	60.5	5.28	0.035	8.14	17.99	123.75	12.735	13.58
R-29	0.635	36.655	0	23.765	9.21	0.03	7.305	3.64	112.75	7.485	15.425
R-30	1.34	45.07	0.02	21.09	4.995	0.01	6.16	5.185	102.35	8.155	13.42
R-31	0.71	33.085	0.005	18.4	2.33	0.02	5.575	1.45	100.45	7.705	1.75
R32	0.55	22.6	0.03	27.115	16.8	0.03	10.295	1.83	144.55	8.23	14.375
R33	0.605	30.885	0.01	24.09	19.165	0.02	11.275	10.235	116.05	7.79	39.39

Table D4: Tabulated Trace Metals Levels in Soil for Background Area Samples

Sample No.	**As (mg/kg)**	**Ba (mg/kg)**	**Cd (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Hg (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Ti (mg/kg)**	**V (mg/kg)**	**Zn (mg/kg)**
IDL**	**0.002**	**0.0002**	**0.0001**	**0.002**	**0.001**	**0.00007**	**0.0003**	**0.001**	**0.0006**	**0.002**	**0.00001**
PQL***	**0.010**	**0.001**	**0.001**	**0.010**	**0.005**	**0.0004**	**0.002**	**0.005**	**0.003**	**0.010**	**0.000**
B1	0.43	28.515	0.005	25.535	2.235	0.01	6.67	0.885	87.7	7.125	2.13
B2	0.375	16.265	0	23.735	1.67	0	4.615	0.625	45.97	4.21	0.405
B3	0.955	13.565	0.23	8.72	1.125	0.185	1.735	2.715	44.64	3.93	10.89
B4	1.1	0.475	22.655	0.155	0.145	0.075	3.205	1.335	1.1	0.06	0.03
B5	0.755	43.505	0.015	15.715	2.675	0.035	10.84	1.03	164	12.59	5.085
B6	0.95	9.96	0.125	9.575	0.85	0.085	2.685	1.785	31.195	2.975	6.805
B7	0.545	24.63	0.02	17.99	1.92	0.015	6.815	0.915	102.75	8.02	1.705
B8	0.595	25.605	0.02	19.005	2.08	0	7.23	0.935	106.75	8.73	2.115
B9	0.61	24.91	0.02	19.965	1.905	0.025	6.585	0.82	96	7.86	1.485
B10	0.475	28.895	0.005	17.425	2.15	0.01	6.82	0.8	94.55	7.565	1.415

B11	0.915	10.595	0	9.675	0.635	0.065	3.745	1.765	26.365	3.02	5.27
B12	0.555	25.52	0.02	19.61	2.03	0.02	6.885	0.845	105.2	8.125	1.59
B13	0.71	26.79	0.015	21.565	2.17	0.005	7.34	0.955	112.95	8.81	3.93
B14	0.66	28.05	0.02	21.965	2.345	0.01	7.55	0.87	118.95	9.225	1.85
B15	0.515	28.23	0	19.435	2.1	0.045	6.625	0.84	90.9	7.425	1.155
B16	0.835	32.35	0.015	25.945	2.575	0.03	8.575	0.96	133.7	10.37	2.34
B17	0.58	33.215	0.03	22.085	2.33	0.02	7.38	0.935	104.4	8.475	1.965
B18	0.66	29.445	0.02	23.6	2.275	0.025	7.915	0.95	120.6	9.42	1.76
B19	0.565	32.34	0.005	22.935	2.3	0.075	7.39	0.885	107.75	8.625	1.92
B20	0.355	16.115	0	22.675	1.765	0	4.58	0.65	46.63	4.2	0.595
B21	1.16	10.705	0.32	10.86	1.345	0.025	2.945	4.42	37.715	3.875	8.235
B22	1.505	79.1	0.095	28.245	8.17	0.055	16.385	14.96	359.6	28.28	32.915
B23	0.38	14.66	0.01	23.945	1.745	0.01	4.99	0.68	52.65	4.815	1.535
B24	0.865	27.545	0.045	24.695	3.975	0.03	8.75	6.455	142.6	11.445	11.11

B28	0.675	29.25	0.02	22.2	3.795	0.045	7.855	5.735	121.45	9.92	10.155
B30	0.505	27.7	0.1	23.705	2.11	0.015	6.035	0.84	85.05	7.095	7.07
B31	0.63	25.205	0.02	25.345	2.245	0.005	6.71	0.77	95.75	7.87	1.1
B32	0.675	25.72	0.025	18.14	2.085	0.055	7.265	0.985	105.3	8.74	1.535

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Appendix E: 3D Spatial Distribution Map of Trace Metals in Dammam Area.

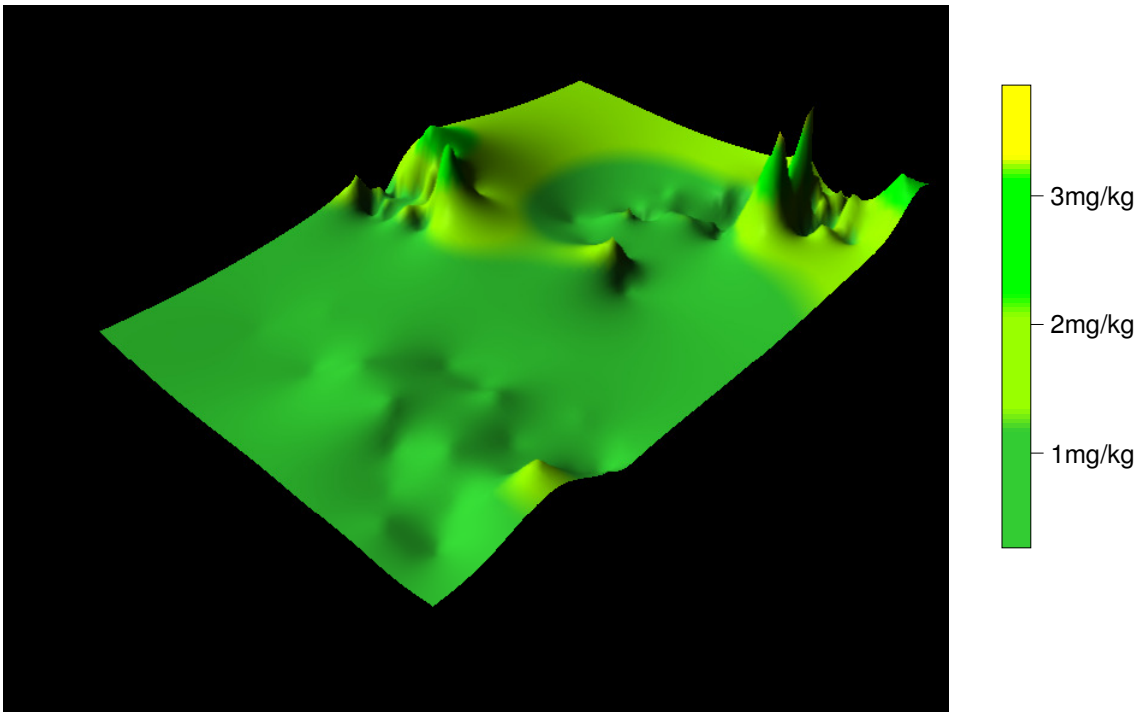

Figure E1: 3D surface distribution of arsenic.

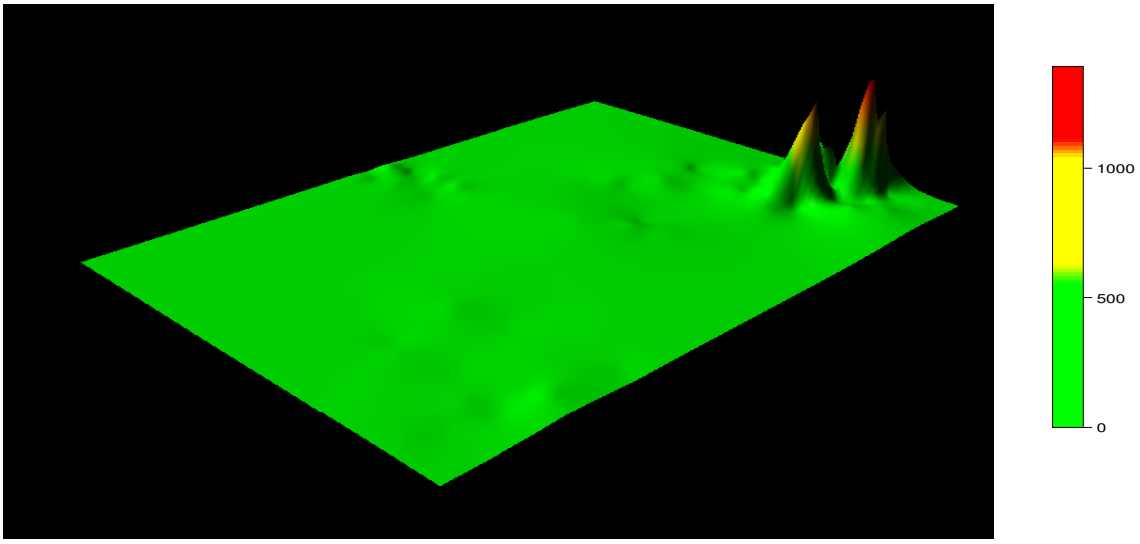

Figure E2: 3D surface distribution of barium.

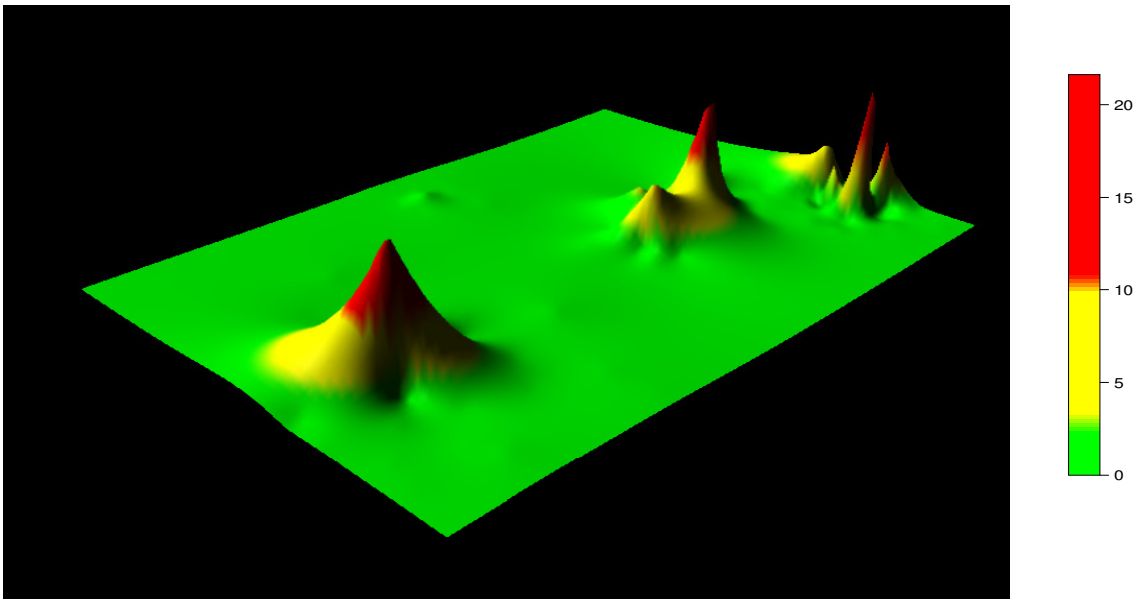

Figure E3: 3D surface distribution of cadmium.

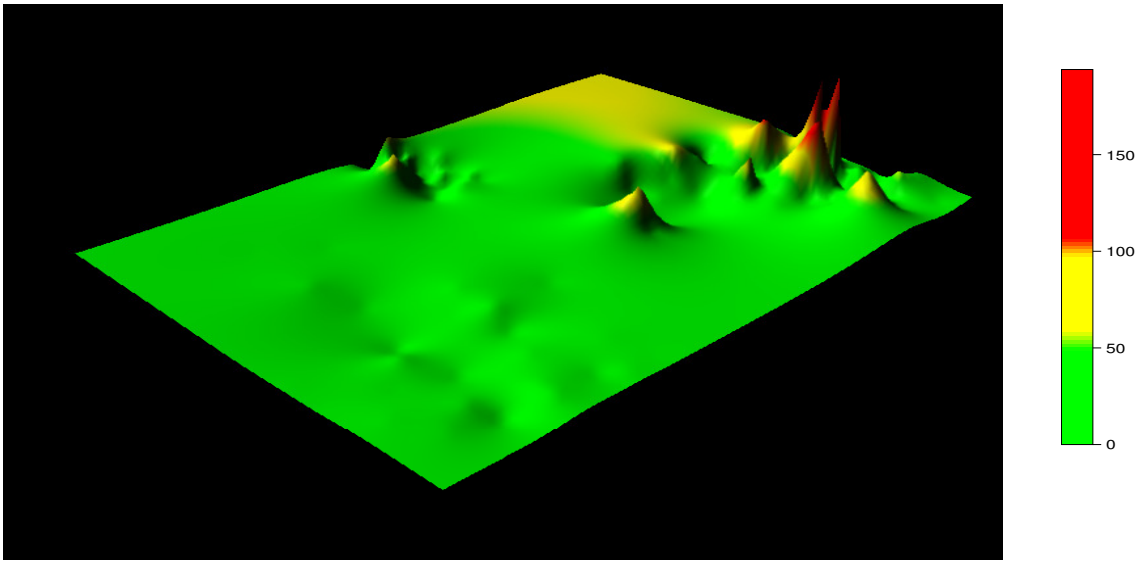

Figure E4: 3D surface distribution of chromium.

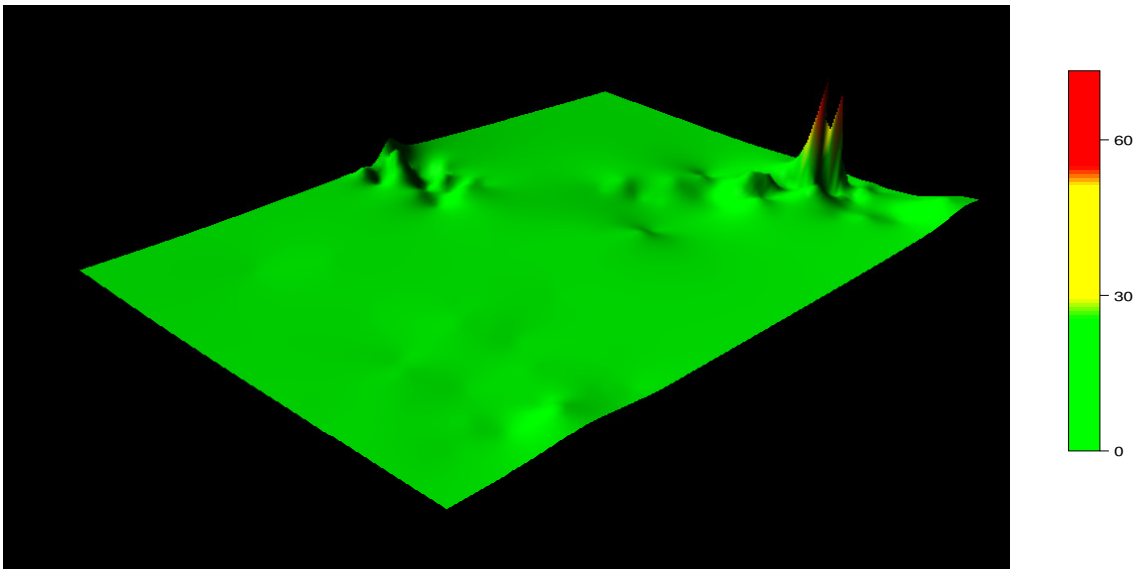

Figure E5: 3D surface distribution of copper.

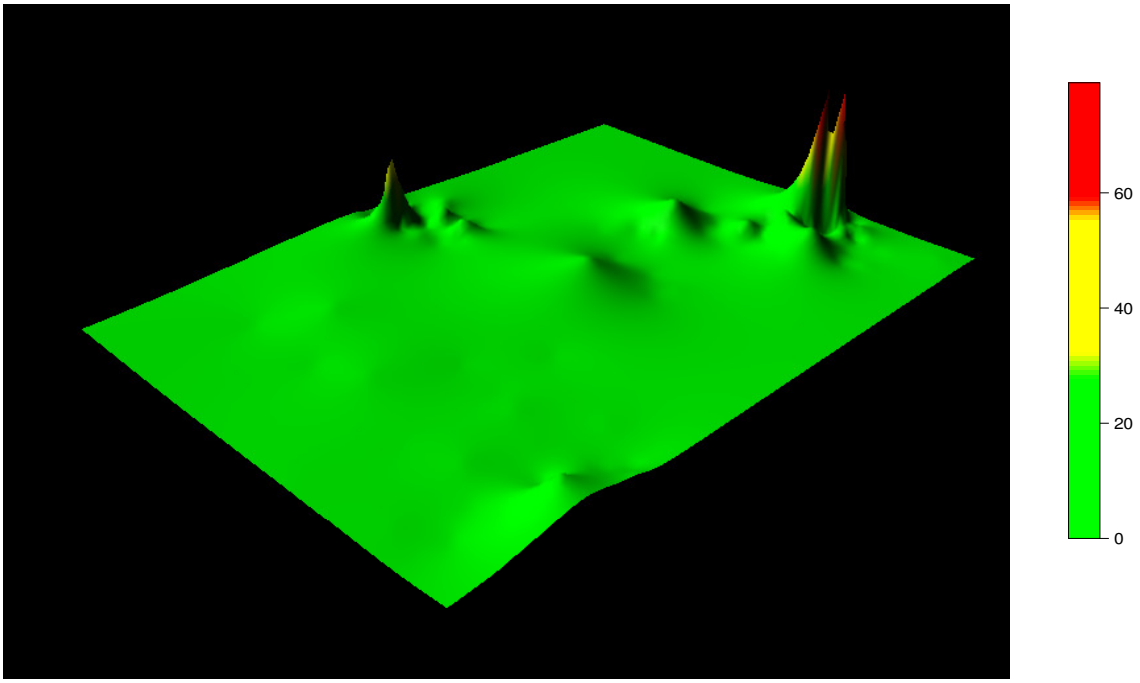

Figure E5: 3D surface distribution of lead.

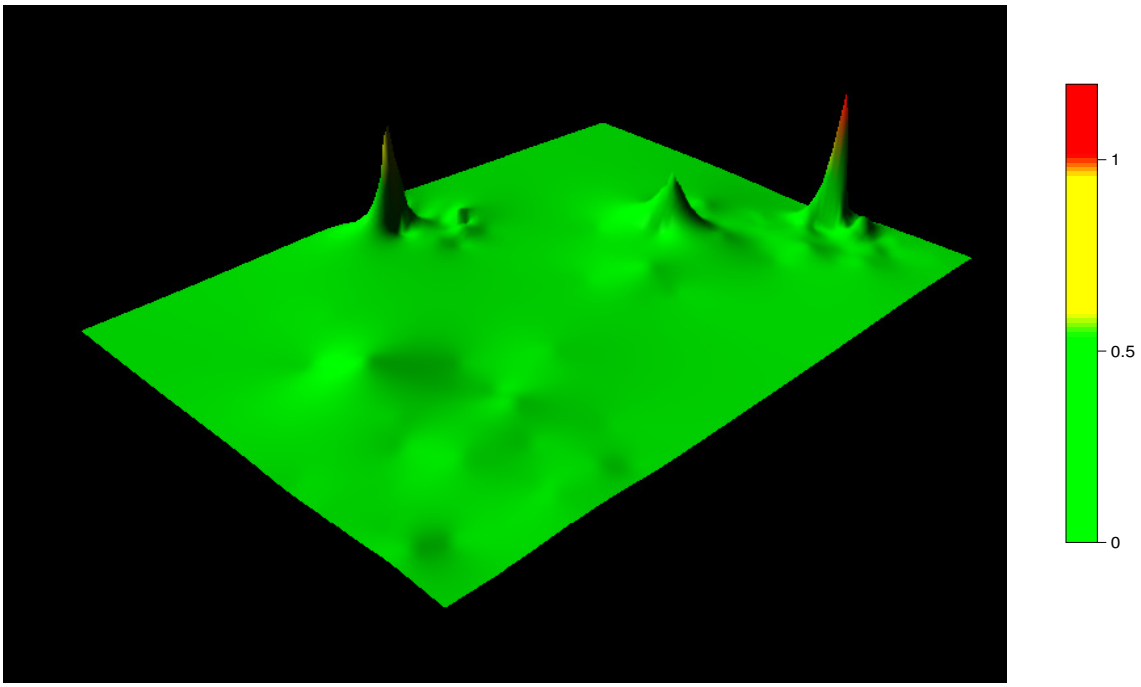

Figure E7: 3D surface representation of mercury.

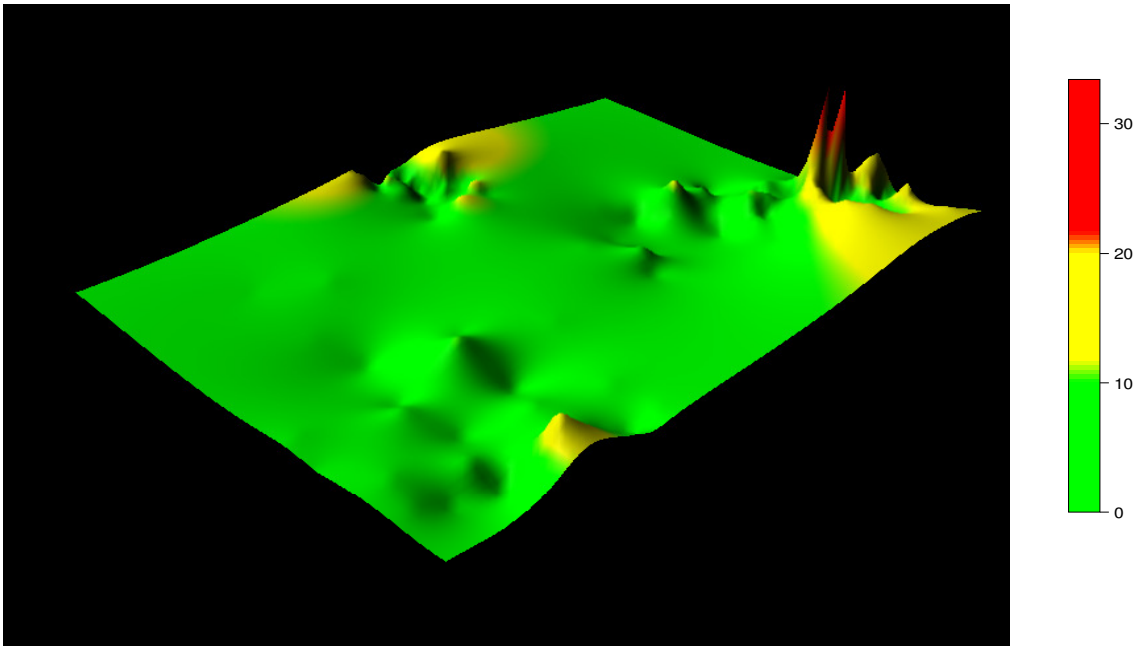

Figure E8: 3D surface distribution of nickel.

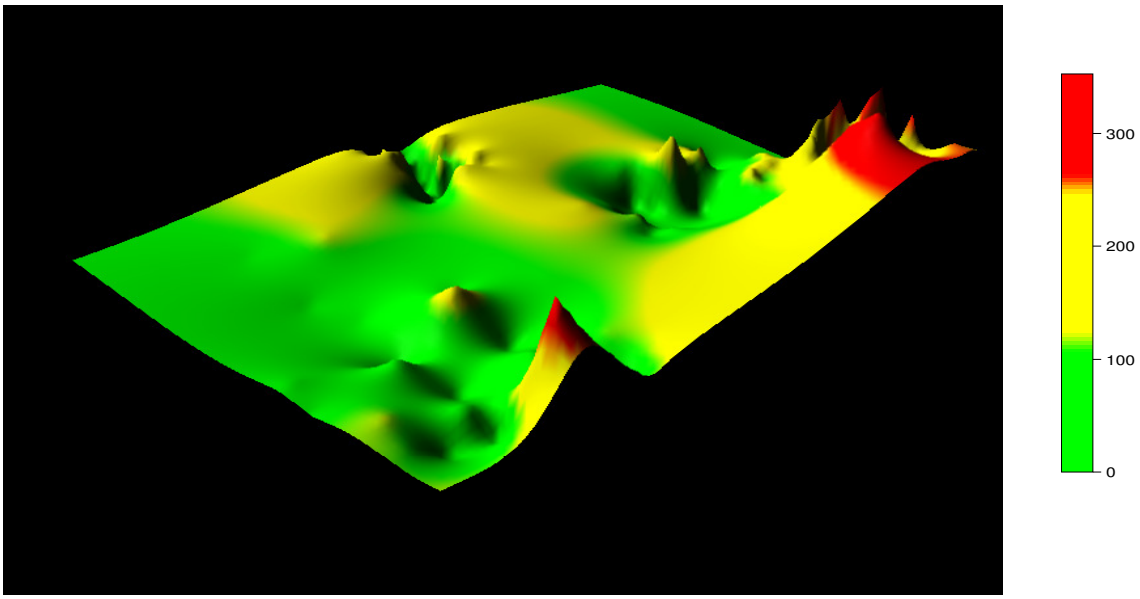

Figure E9: 3D surface distribution of titanium.

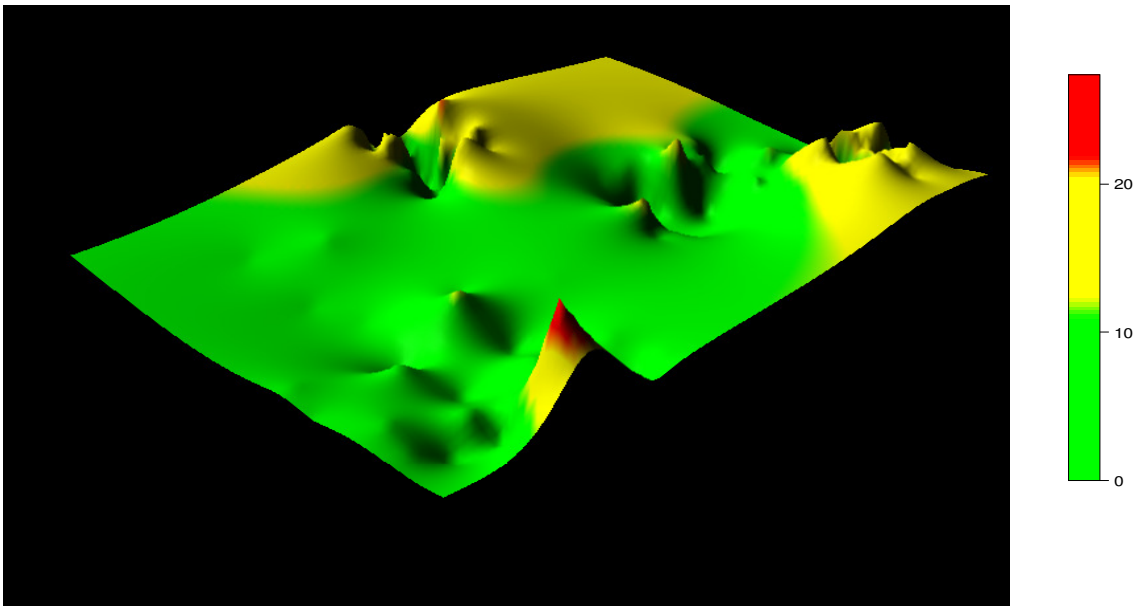

Figure E10: 3D surface distribution of vanadium.

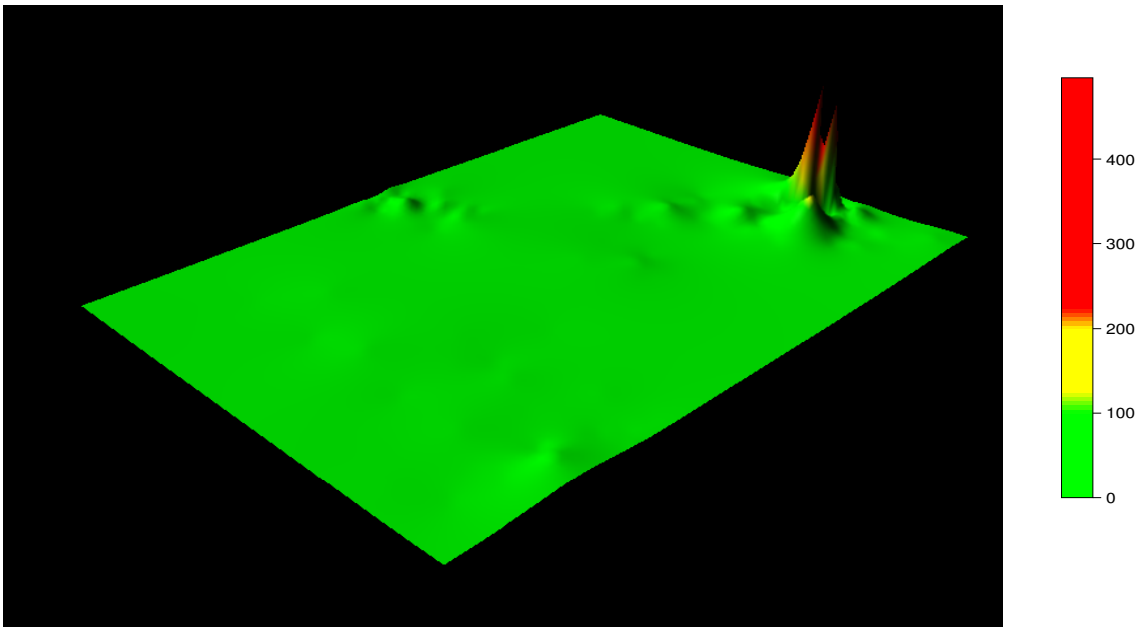

Figure E11: 3D surface distribution of zinc.

VITAE

Name: Adetoro John Adedapo

Nationality: Nigerian

Date of Birth: April 19, 1985.

E-mail: dapoadetoro@yahoo.com

Address: Plot G202, Federal Environmental Quarters, Karu Site, Abuja, Nigeria.

Academic background:

2012- 2014: MS in Earth Sciences (Environmental Science), King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia.

2005- 2009: B.Tech in Surveying & Geoinformatics (Second Class Honours, Upper Division, CGPA of 4.32/5), Federal University of Technology, Minna, Nigeria.

2003-2005: National Diploma in Surveying and Geoinformatics (Upper Credit), Federal School of Surveying, Oyo, Nigeria.